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Elementary, Economic Experiments in Physics
by Reginald F. Melton

INTERNATIONAL CLEARINGHOUSE
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Administrator's Guide

to

ELEMENTARY, ECONOMIC EXPERIMENTS IN PHYSICS

by

REGINALD F. MELTON

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INTRODUCTION

When working as a Science Education Adviser in the Philippines during the sixties Mr. R.F. Melton developed a series of elementary experiments in secondary school physics using simple apparatus. Details for the construction of the apparatus and information about the design of a suitable laboratory, workshop and storerooms were described.

Although the development of the equipment was the primary objective, Mr. Melton considered that it was necessary to give an example of a course in physics for which the apparatus would be suitable. He therefore wrote a Student Guide and a Teacher's Guide to such a course in addition to a Guide to the Apparatus and an Administrator's Guide.

It seemed to us in the Centre for Educational Development Overseas that science advisers and curriculum teams working in developing countries might find these guides of considerable interest and value, so the Centre arranged for a limited number of copies to be made available. It may also be of interest to note that a study called Inexpensive Science Teaching Equipment Worldwide (IS-2), is being published separately and will complement these volumes published by CEDO. This study was conducted by Dr. J. David Lockard and Mr. R. F. Melton during 1971 at the University of Maryland Science Teaching Center, U.S.A.

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Author's Foreword

"To all my friends overseas"

The author spent ten years in developing countries, working for the British Government in Turkey and the Philippines and for the Ford Foundation in Pakistan. During that time he became acutely aware of the problems facing developing countries in the field of science education, and it is his hope that 'Triple E Physics' will contribute in some small way to the major tasks that lie ahead. 'Triple E Physics' emerged from a wealth of experiences shared with educators, scientists and friends overseas, and it would seem fitting that this book should be dedicated to those many friends who made the author's work in developing countries such a rewarding experience.

The author was until recently the Associate Director of a project for the development of "Improvised Science Teaching Equipment Worldwide" at the Science Teaching Center of the University of Maryland (USA).

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1. WHY 'TRIPLE E PHYSICS'?

When the Physical Science Study Committee (PSSC) began its work in the United States in late 1956 it started a movement which is now revolutionizing the teaching of science. Breaking away from traditional ideas the PSSC will be remembered in the same spirit as the first four minute mile, as a foretaste of things to come.

Since then science projects have mushroomed, leaving us with little doubt that we are at the beginning (not the end) of a period of revolution in science teaching. Teachers in developing countries are daily growing more and more aware of the new ideals and methods being generated, but far too often are unable to benefit from the dynamic winds of change sweeping through the field of education. The reasons for this are fairly clear.

Adoption of new programs in Developing Countries makes little sense if such programs are either unsuited to a country's academic needs or are beyond what a country can reasonably afford. Teachers are realistic in such matters and recognize the need to modify existing programs before adoption, but it is at this stage that problems arise. What parts of a program are suitable for adoption? What apparatus should be purchased, given limited financial resources? What does one do if apparatus requires sophisticated laboratory facilities? How far can a program be modified without destroying its essential character? It is usually at such a stage that frustration sets in. What can teachers do alone without the essential guidance and support needed to modify materials, and without the necessary resources to develop facilities? It was very much with such questions in mind that 'Triple E Physics' was developed.

2. WHAT IS 'TRIPLE E PHYSICS'?

'Triple E Physics' is a package of materials developed to help educators introduce a scientific, inquiring approach into the teaching of physics in Developing Countries. Low cost apparatus, designed for production in local workshops and for use under simple laboratory conditions, is fundamental to the whole program. Equally important, however, is the integration of materials ranging from guidance for students, teachers and technicians to the provision of resource materials for administrators. The development of laboratories, workshop facilities, trial programs and in-service training are all considered equally important parts of the development machinery.

More specifically 'Triple E Physics' is a package consisting of a Student Guide, Teacher's Guide, Apparatus Guide and Administrator's Guide.

The Student Guide is based on the premise that high school students in Developing Countries, like students everywhere, need to learn to understand what scientific knowledge really means and how it is built up from developing theories and experiments. They must learn to understand the uncertainties of science, and yet to appreciate its paramount importance to society. Such understanding can be developed through an inquiring approach, placing the pupil in the position of the researcher and the teacher in the position of consultant. This is not the only way of approaching the problem, but it is a technique which has already shown considerable promise. Above all it is an approach which has been found to provide essential motivation to the majority of students, who so often in the past have been bored and disillusioned by traditional, pedagogic methods of teaching, but have been excited and awakened to the allure of science by an attitude of discovery.

The Student Guide therefore presents a series of experiments which are fundamental in nature, and as such are ideal for introducing new concepts. Educators may select individual experiments to fit into their existing curriculum, or, since the experiments have been developed as a logical sequence, may choose to offer the experiments as a whole, as an introductory course in physics, which is complete in itself.

The Teacher's Guide is based on the knowledge that very few teachers are willing to adopt new philosophies without considerable assistance.

At least the traditional, pedagogic method of teaching gives a teacher confidence, even if it offers very little else, so it is important to insure that a teacher receives sufficient guidance to enable him to proceed in new ways with confidence. For this reason the Teacher's Guide contains detailed results of actual experiments along with relevant comments and suggestions.

The Apparatus Guide describes how equipment may be made in the simplest of workshops, and as such is fundamental to the whole program. The apparatus it describes has been developed specifically for Developing Countries in the realization that they have very limited economies, and that by necessity their schools have not only limited laboratory facilities, but also stringent financial resources. Apparatus has therefore been designed for economy, for ease of operation under limited laboratory conditions, and for ease of production under local conditions.

Apparatus has been designed specifically with students and teachers in mind, and can be made with the simplest of handtools. This has the advantage that cottage industries will have no difficulty in adapting the designs to their own requirements, whereas the reverse situation would be much more difficult.

It is in fact envisaged that cottage industries will be the major producers of equipment for 'Triple E Physics', and with this in mind a few blue-prints have been added to describe the more complex items. However, sophisticated techniques and machinery are not required, even for the most complex items, and good local workshops should have little difficulty in handling the work.

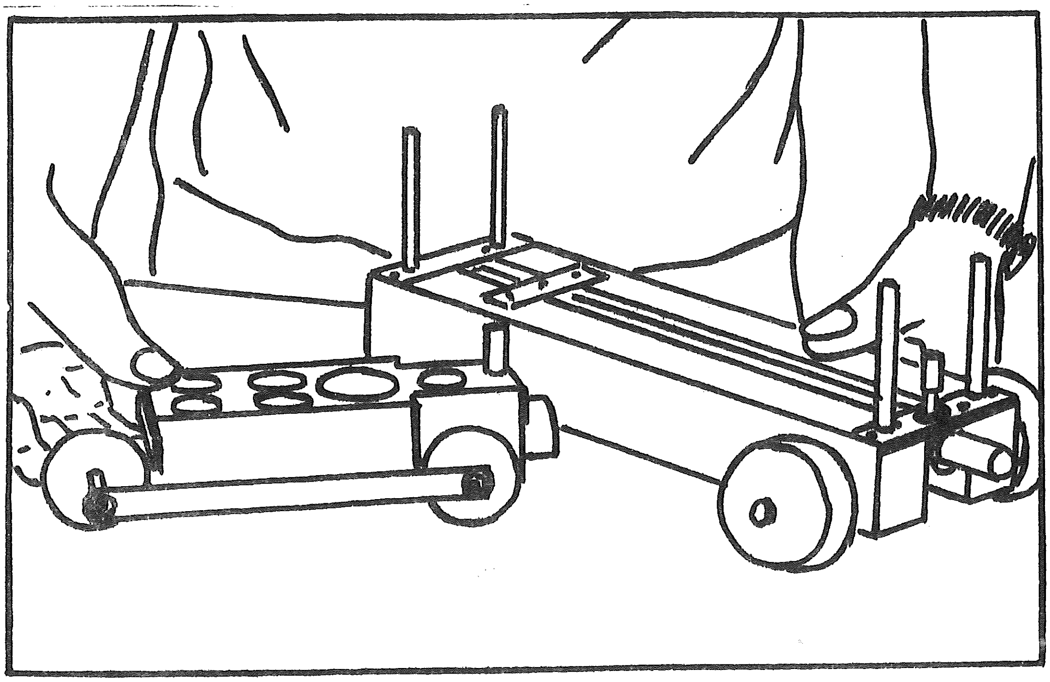
The Administrator's Guide not only includes details of laboratory plans, workshop facilities and methods of production, but also a breakdown on the type of overall planning that is so essential to the implementation of any new program. Administrators must be prepared to determine for themselves what experiments might realistically be included in their curricula, what in-service training will be required, what apparatus production will be necessary and what laboratory development will be essential. The Administrator's Guide has been written specifically to help answer such questions, and as such is a crucial component of 'Triple E Physics'.

3. APPARATUS DESIGNS

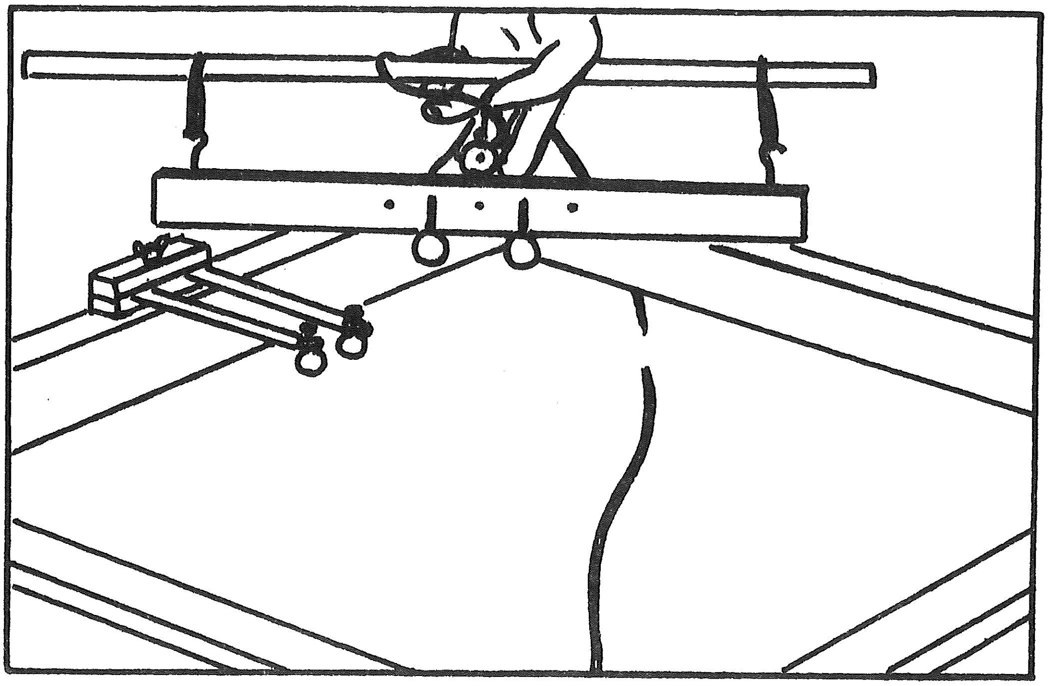
The Apparatus Guide contains three types of designs: modifications of existing item types, completely new items, and items which may be grouped into kits. All these designs take into account not only the raw materials and technical skills that are available in Developing Countries, but also their limited economies. The following examples should illustrate these points.

3.1 Modification of Existing Item Types

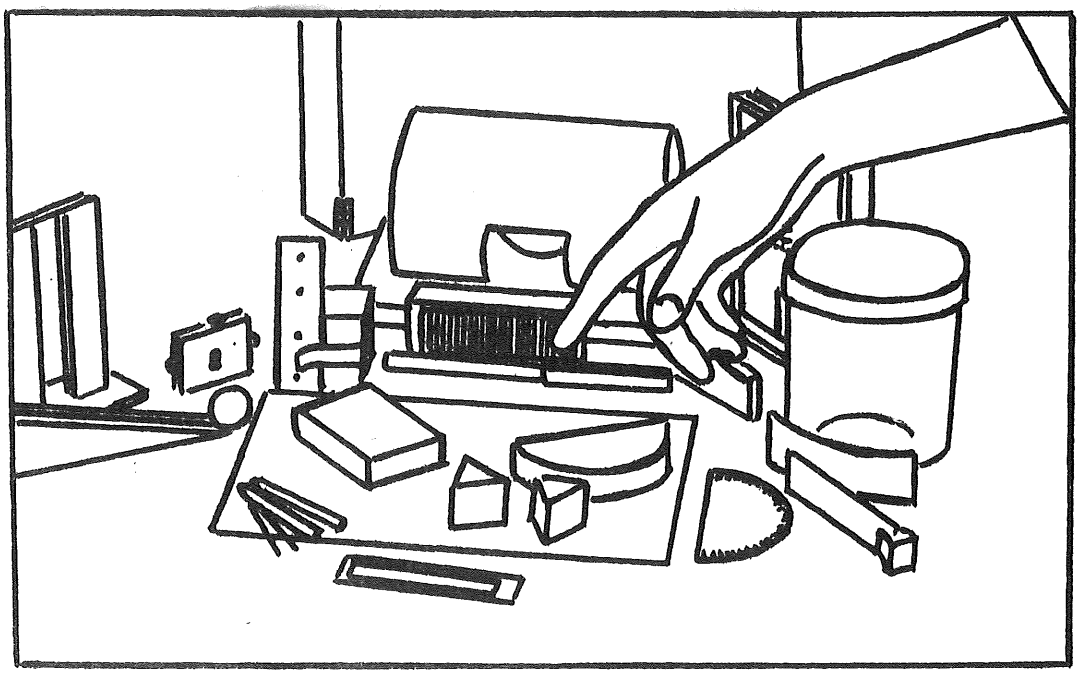
In designing a force and motion cart it is recognized that ball bearing wheels are often unavailable in Developing Countries, or if available may be extremely expensive. The design offered therefore makes use of simple pivot-type wheels which can readily be produced under local conditions. Frictional effects with the cart are reduced by using an inclined slope to compensate for friction.



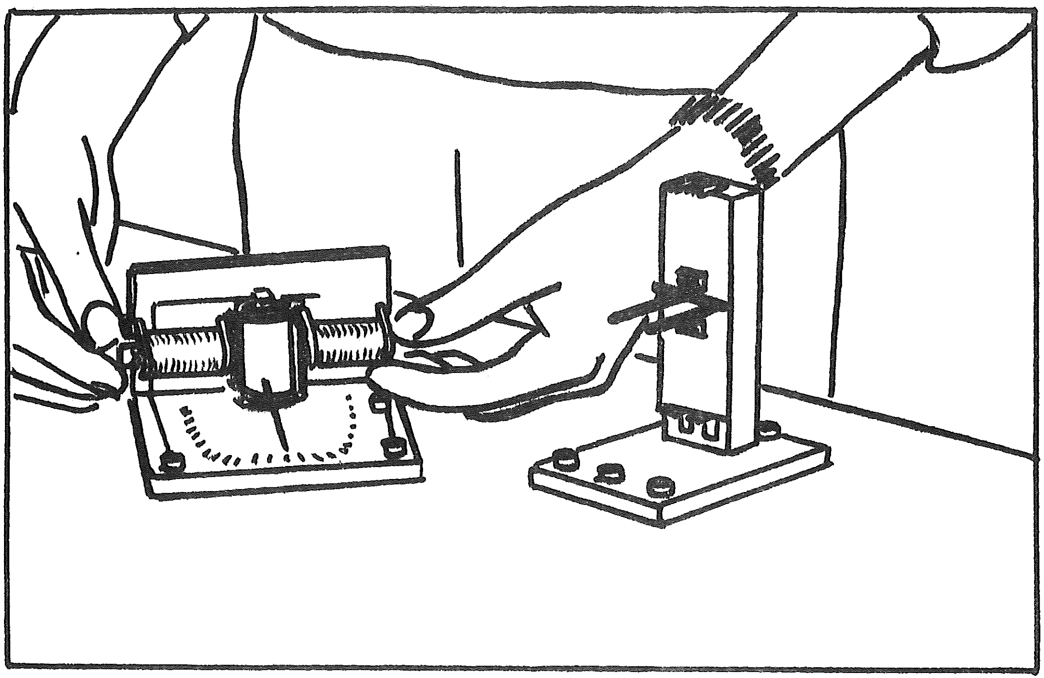
Similarly small electrical motors are often unavailable, or, if available, are expensive. The design of the ripple tank vibrator therefore describes a mechanical type of vibrator rather than an electrically driven one. This simplified vibrator still permits the realization of a whole range of wave motion experiments with the ripple tank.

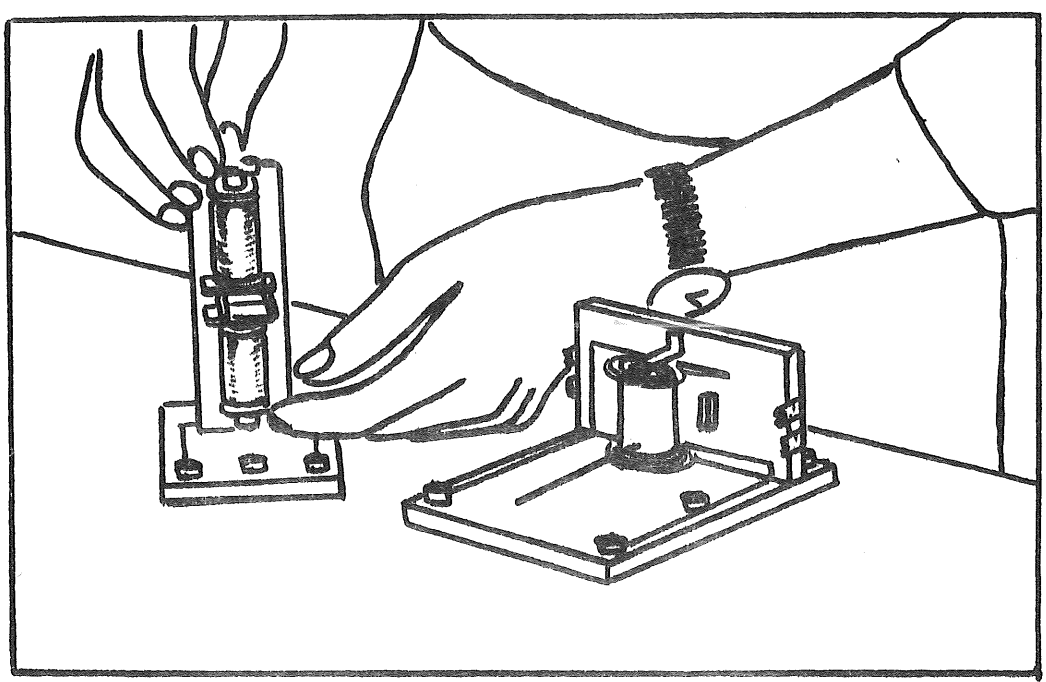


Production of optical prisms and lenses from glass requires specialized technical skills, but the Apparatus Guide describes how these may be made from plastics (acrylic) with no more than a hacksaw, some sandpaper and a little metal polish.



High quality steels and alnico alloys are often extremely difficult to obtain in Developing Countries, and the production of high quality magnets becomes a major problem. Electromagnets, however, may readily replace normal magnets, and designs making use of these in such items as moving coil galvanometers and magnetic field apparatus are included in the Apparatus Guide.





3.2 New Item Types

Although some economy may be made by modifying existing item types, much greater economy results if new apparatus is designed to illustrate basic concepts. For example, the concept that bodies fall with the same gravitational acceleration, if unaffected by friction from the air, may be demonstrated at considerable expense with the help of an evacuated tube, a feather and a piece of metal (the usual "guinea and feather experiment"). However, it may be presented equally well with a stone and a sheet of paper. The Student Guide lists materials such as the paper and stone, along with other items of apparatus, and indicates how these may be used to develop particular concepts. Thus relative motion is studied with pieces of paper, while forces are studied with strips of metal, sponge rubber, modelling clay, wire and syringes.

3.3 Kits

The Student Guide groups activities together by concept, introducing each with a list of apparatus (the kit) required to study the concept. This means that although a single item (e.g., ripple tank) may be relatively expensive, the cost per experiment is relatively low since the accessories make it possible to perform a whole series of experiments.

4. APPARATUS REQUIREMENTS AND COSTS

The following lists indicate the total equipment that would be required by a class of 32 students undertaking all the experiments presented in 'Triple E Physics'. It is strongly recommended that laboratory classes should not exceed 32 students per teacher, and that students should normally work in pairs, although occasionally (e.g., for ripple tank work) groups of 4 are permissible. It follows that equipment is required in multiples of 16, and occasionally 8, for class experimentation. If only one item of equipment is listed in a particular kit this indicates that the item is to be used on a rotational basis by students, or as a demonstration item by the teacher. Clearly, teachers and administrators will wish to adjust these lists according to the number of experiments to be adopted in their curricula and according to the class size envisaged.

It is suggested that equipment producers should pack the apparatus in class kits, that is 16 (or 8, etc.) pieces of the same equipment per box as indicated below. If the kits are packed in shallow cardboard boxes from which the top and half the front may readily be removed the boxes will serve as storage trays, thus permitting a teacher to select an appropriate set of apparatus with the minimum of inconvenience. The teacher will probably find it convenient to store the apparatus in the same order as that given in the following lists.

It is of interest to record that 3 sets of equipment for 'Triple E Physics' were produced and tested in the Philippines between 1966 and 1969. The cost of the raw materials required to produce the apparatus was estimated on this basis, and it was determined that equipment listed below could be produced at a cost of $207 dollars (1969 estimate). This does not include the cost of labor which

could more than double the final cost involved. Clearly costs vary from country to country, but, taking into consideration the 139 activities which may be undertaken with the 'Triple E Physics' materials, it would appear that there is some justification for suggesting that the experiments are economic in nature.*

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* The 139 activities include:

MEASUREMENT	19 activities
FORCES AND MOTION	47
WAVE MOTION	17
OPTICS	33
ELECTRICITY	23

Taking into account the raw material cost only, the total 'Triple E Physics' materials cost:

$207 dollars per class of 32 students per 139 activities

or $0.07 dollars per student per activity.

4.1 Apparatus Requirements

Item No.	Apparatus	Quantity
1.10/01	Triangulation Device	16
1.10/02	Displacement Block	16
1.20/01	Balance	16
1.20/02	Box of Weights	16
1.20/03	Microbalance	16
1.30/01	Ticker Tape Timer	16
	or	
[1.30/02	Alternative Ticker Tape Timer (Blue-Print)]	
1.40/01	Relative Motion Frame	16
2.10/01	Wire Extender	1
2.10/02	Wire Spring, Copper	16
	Wire Spring, Steel	16
2.10/03	Rebound Apparatus	1
2.10/04	Spring Balance, 1 Newton	16
	Spring Balance, 10 Newtons	16
2.10/05	Puck	1
2.10/06	Friction Tube with Stand	1
2.20/01	Simple Cart	16
	or	
[2.20/02	Cart (Blue-Print)]	
2.20/03	Inclined Plane	16
2.20/04	C Clamp	16
2.40/01	Inertial Balance	16
2.50/01	Elastic Collision Runway	-
2.60/01	Centripetal Force Apparatus	8
2.70/01	Dynamo/Motor	1
	or	
[2.70/02	Dynamo/Motor (Blue-Print)]	
2.70/03	Simple Machine	16
3.10/01	Ripple Tank	8
3.10/02	Ripple Tank Accessories	8
3.10/03	Stroboscope	8

Item No.	Apparatus	Quantity
4.10/01	Light Source with Base (8 sources already available with Ripple Tanks)	16
4.10/02	Slit/Aperture Combination	16
4.10/03	Mirrors, Plane	16
	Mirrors, Curved	16
4.10/04	Optical Board with Pins	16
4.10/05	Optical Prisms, Rectangular	16
	Optical Prisms, Triangular	16
	Optical Prisms, Semi-circular	16
4.10/06	Refraction Model Apparatus	16
4.10/07	Screen with Holder	16
4.10/08	Filter (Red)	16
4.20/01	Single and Double Diffraction Slits or	16
[4.20/02	Adjustable Diffraction Slit (Blue-Print)]	
4.20/03	Simple Diffraction Holes	16
4.30/01	Multiple Slit	16
4.30/02	Lens Holder	16
4.30/03	Interference Strips, Copper	2
	Interference Strips, Steel	2
5.10/01	Dry Cell Holder with Cells	32
5.10/02	Bulb Holder with Bulb	64
5.10/03	Switch	32
5.10/04	Multipurpose Coil with Cores	32
5.10/05	Compass	32
5.10/06	Magnetizing Coil	1
	Cylindrical Magnets (5 cms long, 0.8 cms diameter)	32
5.10/07	Tangent Galvanometer	16
5.10/08	Magnetic Field Apparatus or	16
[5.10/09	Magnetic Field Apparatus with Multipurpose Coils] (Multipurpose Coils already available)	
5.10/10	Moving Coil Galvanometer or	16
[5.10/11	Moving Coil Galvanometer with Multipurpose Coils] (Multipurpose Coils already available) or	
[5.10/12	Moving Coil Galvanometer (Blue-Print)] (Multipurpose Coils already available)	

Item No.	Apparatus	Quantity
5.20/01	Neon Bulb Holder with Bulb	16
5.20/02	Electricity Tester	16
5.20/03	Resistor Holder with Resistor	16
5.20/04	Chemical Cell	16

4.2 Additional Requirements

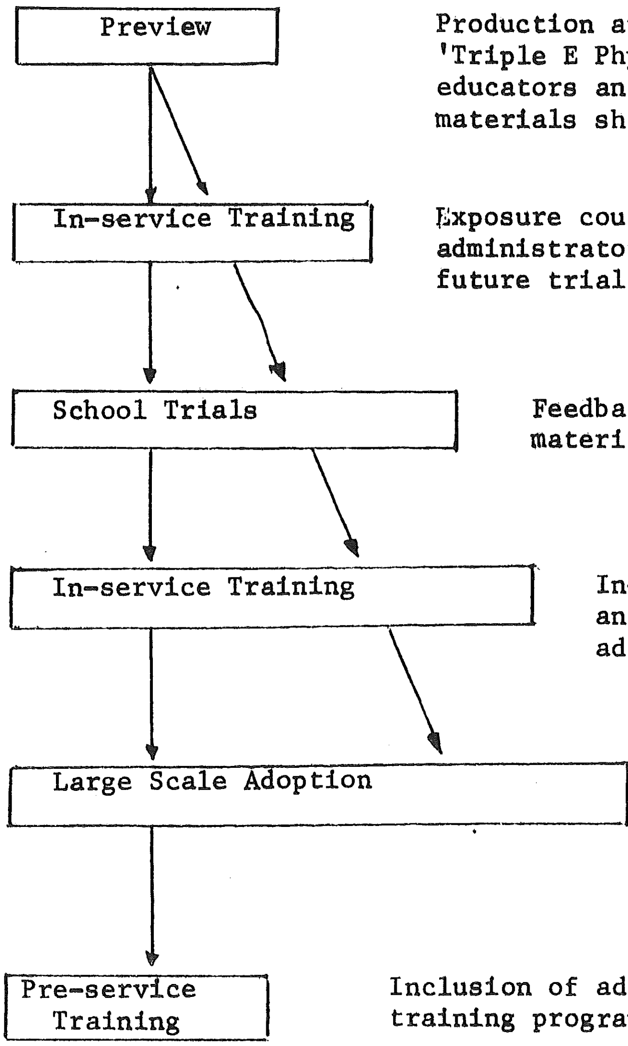
Apparatus	Quantity
Ball Bearings, diameter 0.8 cms	16
Ball Bearings, diameter 1.2 cms	16
Ball Bearings, diameter 2.4 cms	16
Balls, Brass, Centrally Drilled, diameter 1.2 cms	16
Balls, Brass, Centrally Drilled, diameter 2.4 cms	16
Barriers, Wooden (8 x 3 x 0.8 cms)	16
Blocks, Wooden (10 x 6 x 4 cms)	32
Bottle Tops	8
Bulbs (2.5 volts, 0.3 amps)	64
Bulbs (6.2 volts, 0.3 amps)	16
Cardboard Strips (10 x 2 cms)	16
Chalk	1 box
Container, Plastic (approximately 10 cms deep, 10 cms diameter)	2
Cork (1 cm diameter, 0.5 cms deep)	8
Cubes, Sponge Rubber (5 x 3 x 2 cms)	32
Cubes, Wooden (4 x 4 x 4 cms)	32
Hacksaw	4
Hammer	4
Lead Strips (10 x 5 x 0.1 cms)	8
Lenses, Hand (focal length 10 to 20 cms)	16
Metal Strips, Alloy (20 x 1.5 x 0.05 cms)	16
Metal Strips, Lead (20 x 1.5 x 0.05 cms)	16
Metal Strips, Steel (20 x 1.5 x 0.05 cms)	16
Modelling Clay	1 kgm
Nails (1 cm long, approximately)	1 kgm
Nails (10 cms long, 0.7 cms diameter)	1 kgm
Needles (3 cms long)	50
Olive Oil	0.5 liters
Paper, Carbon (22 x 28 cms approximately)	50 sheets
Paper, Plain White (22 x 28 cms approximately)	2 reams
Paper Clips (100)	4 boxes
Plastic Strips (10 x 2.5 cms)	32
Protractors	16
Rings, Metal (diameter 0.5 cms)	16

Apparatus	Quantity
Rubber Bands (100)	8 boxes
Rubber Bands, Chain of (40 to 50 cms long)	40
Rulers, Meter	16
Salt	0.5 kgm
Sandpaper (20 x 20 cm approximately, varied grades)	32 sheets
Screws, Cup	200
Set Squares (approximately 10 x 17 x 20 cms, or bigger)	32
Soap Solution (dish washing liquid)	2 bottles
Spring, Door (35 cms long, 1 cm diameter approximately)	1
String, strong and thin (50 meters)	2 balls
Syringe, Plastic (without needle, minimum diameter 1.5 cms, minimum volume 10 ccs)	16
Thumb Tacks (100)	2 boxes
Ticker Tape (25 meters)	4 rolls
Vinegar	4 liters
Wire, Copper (Plastic or Cotton Covered, #24)	2 kgm
Wire, Magnet (#24)	1 kgm
Wire, Magnet (#26)	0.5 kgm
Wire, Steel (#26)	0.5 kgm
Wire, Steel (#30)	0.5 kgm

5. IMPLEMENTATION OF 'TRIPLE E PHYSICS'

It is possible for a well motivated school to adapt the whole 'Triple E Physics' program without outside help. It would of course be responsible for its own apparatus production, laboratory development and teacher orientation, and there is no doubt that this would be a major task.

In general it is hoped that science education centers, supervisors and administrators will provide teachers with the help that is needed on a regional basis. Such individuals and centers can determine which experiments might best be integrated into the curriculum. They can designate local workshops for apparatus production and arrange some system of technical guidance and quality control. They can survey existing laboratory facilities and recommend essential developments. In addition they can arrange for teachers to receive appropriate in-service training in the materials, insuring a well orientated teacher returns to the classroom. It is recommended that materials should be introduced in the first instance on a trial basis, for however well the materials might have worked elsewhere it is important to determine whether students have problems with the materials, and whether teachers are able to handle them adequately. It is important to recognize production problems at an early stage, and problems such as these are best detected by a limited trial of the materials. The following chart summarizes the processes which might be introduced to insure a successful implementation of the materials.



Preview: Production and testing of one complete set of 'Triple E Physics' materials by small groups of educators and technicians. Decision as to which materials should be adopted in existing curriculum.

In-service Training: Exposure courses for limited number of teachers, administrators and technicians to be involved in future trials and subsequent in-service training.

School Trials: Feedback to be obtained on all aspects of materials, modifications being made as required.

In-service Training: In-service training for teachers, administrators and technicians to be involved in large scale adoption of materials

Large Scale Adoption: Large scale adoption of materials as desired

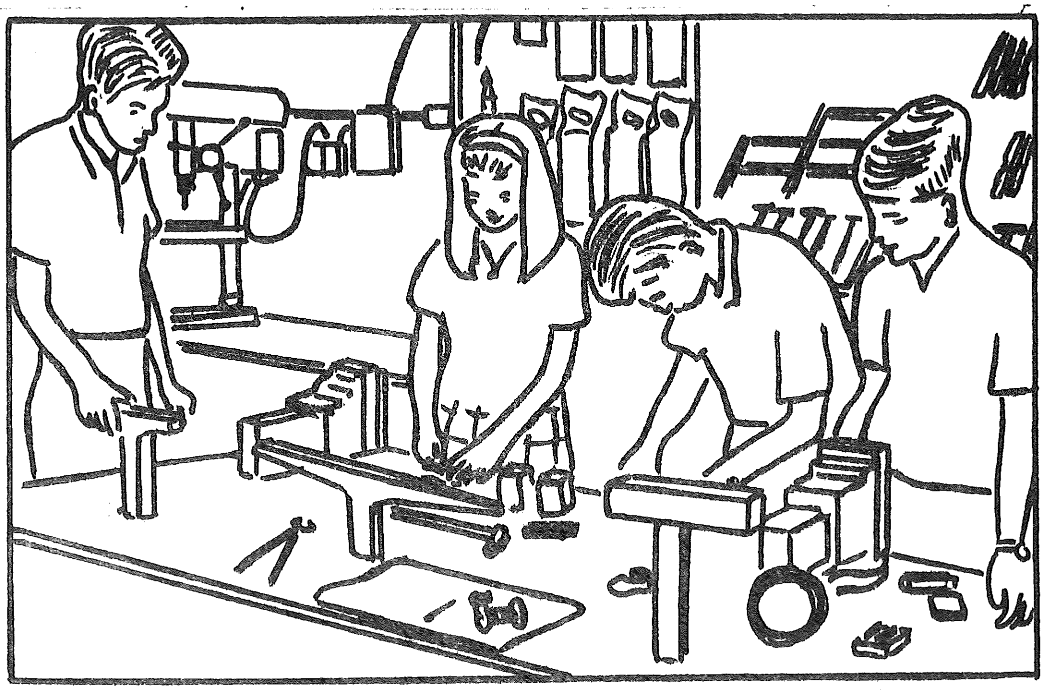
Pre-service Training: Inclusion of adopted materials in regular pre-service training programs.

6. APPARATUS PRODUCTION

In looking around for suitable apparatus producers it is almost certain that administrators will give some thought to the use of students and teachers, technical institutions, factories and cottage industries, and a brief comment on each might be helpful.

6.1 Student and Teacher Production

Students and teachers are encouraged to make items for themselves, for apparatus development can bring both students and teachers into close contact with the realities of science, relating science and technology in the simplest of ways.



However, this does not mean that students and teachers should attempt to produce all their own apparatus requirements. It is recognized that teachers have specific curricula to follow, and that "class hours" available for such work are very limited. It would therefore appear to be more realistic to look to other sources for mass production of apparatus.

6.2 Technical School Production

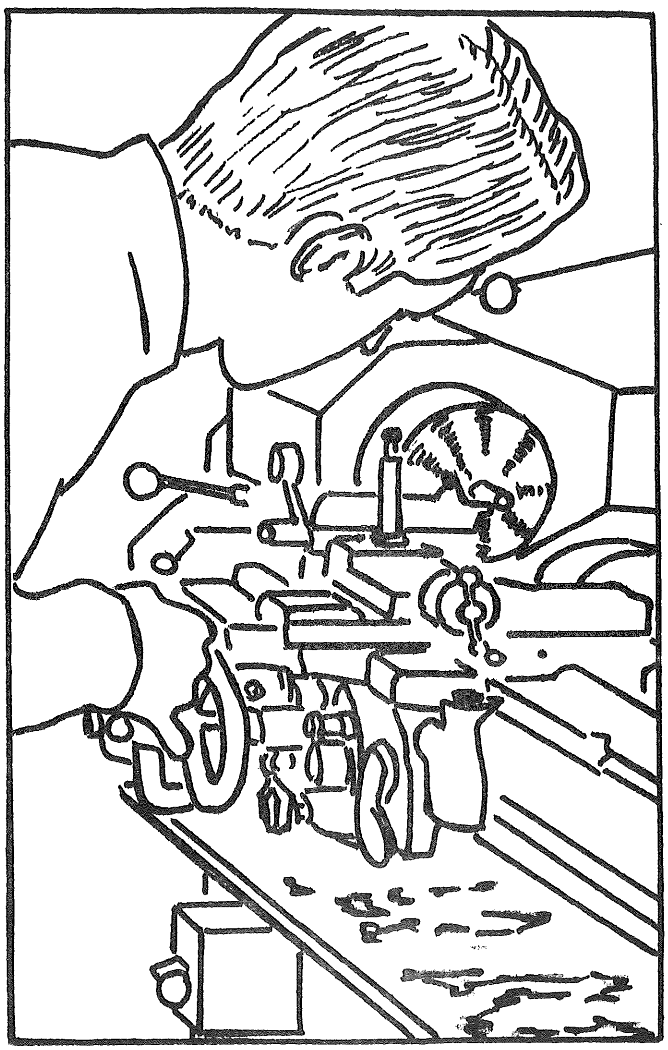
Another alternative often considered is the use of students in technical schools as production units. Any such plan should again take into account the fact that technical institutions are primarily training centers and not mass-production units. However, valuable training in scientific instrumentation can be gained by involving students in some form of apparatus production.

6.3 Factory Production

Many countries look to new government factories to solve their equipment problems, and here, too, one might add a word of caution. Such plans require considerable input in the way of machines and training of personnel, while care must be taken to avoid the typical red tape and bureaucracy that so often accompany government-run organizations.

6.4 Cottage Industry Production

The fourth alternative, and in many ways the most desirable, is to look to the so-called cottage industries which exist in developing countries. In these small industries, there are many workshops with hand tools and simple lathes and drill presses, and there are enough semiskilled workers to operate them. So long as apparatus is designed with these conditions clearly in mind, it can be produced without building new factories or undertaking major training programs. At the same time useful work can be offered to a number of relatively underemployed people.



7. WORKSHOP FACILITIES

7.1 Handtools

Any workshop wishing to produce reasonable quantities of equipment will wish to procure the majority of the following handtools.

Chisels (Wood)	
3, 6, 9, 12, 15, 18, 21, 24 mms (i.e., 1/8", 1/4", 3/8", 1/2", 5/8", 3/4", 7/8", 1")	8
Cutters	
Bench Shears, 3 mm (1/8")capacity	1
Glass Cutter	1
Knife	1
Scissors, 200 mm (8")	1
Snips (Tinmans), Straight, 200 mms (8")	1
Snips (Tinmans), Curved, 200 mms (8")	1
Taps and Dies, 3 to 12 mms (1/8" to 1/2") set	1
Drills and Borers	
Cork Borer Set	1
Countersink, 90°	1
Metal Drill Holder (Electrically Driven), Capacity 6 mm (1/4")	1
Metal Drills, 0.5, 1, 2, 3, 4, 5, 6, 7 mms (i.e., 1/32", 1/16", 3/32", 1/8", 5/32", 3/16", 7/32", 1/4") set	1
Wood Brace with Ratchet, 250 mms (10")	1
Wood Augur, Bits 6, 12, 18, 24 mms (i.e., 1/4", 1/2", 3/4", 1")	4
Files (Double Cut)	
Flat, 100 mm, 200 mm (4", 8")	2
Round, 100 mm, 200 mm (4", 8")	2
Triangular, 100 mm (4")	1
Hammers	
Ball Pein, 125, 250, 500 grams (1/4, 1/2, 1 lbs)	3
Claw 250 grams (1/2 lb)	1
Measuring Aids	
Caliper (Inside)	1
Caliper (Outside)	1
Caliper (Vernier) may replace above two items	1
Dividers, 150 mms (6"), Toolmakers	1
Meter, Electrical (Multipurpose - volts, ohms, amps, etc.)	1
Meter Stick	1
Scriber	1
Square, Carpenter's, 300 mm (12") blade	1
Square, Try, 150 mm (6") blade	1

Planes	
Spoke Shave, 18 mm (3/4")	1
Wood Smoothing Plane	1
Pliers	
Combination, 150 mm (6")	1
Long Nose, 150 mm (6")	1
Side Cutting, 150 mm (6")	1
Saws (Metal)	
300 mm (12") blades	1
(Wood)	
Cross Cut, 600 mm (24")	1
Hand Rip, 600 mm (24")	1
Tenon, 200, 300 mm (8", 12")	2
Screw Drivers	
100 mm (4"), with 2 and 3 mm tips	2
150 mm (6"), with 5 mm tip	1
200 mm (8"), with 7 mm tip	1
Vices	
Engineers Bench Vice, 75 mm (3")	2
Wood Work Bench Vice, 150 mm (6")	2
Wrenches (Adjustable)	
100, 150, 200 mm (4", 6", 8")	3
Miscellaneous	
Goggles, Glass (pair)	1
Oil Can, 1/2 litre (1 pint)	1
Oil Stone, double faced	1
Punch, Center	1
Soldering Iron (60 watts, 100 watts)	2
Stamps, 3 mm (1/8") set of letters and numbers	1

7.2 Machine Tools

Machine tools are not essential for the production of 'Triple E Physics' equipment. However, they do make the process of production so much quicker and easier, and there is no doubt that cottage industries will find the items listed below a distinct asset.

Specifications indicated below are approximate, and only intended as a guideline . 3 phase motors are preferred, being cheaper and more economical to run, but all machines may be bought with either 1 phase or 3 phase motors depending on the supply available. Voltage depends on the local supply, while horse power is a matter of personal preference, but the lower the power the cheaper the machine.

1 Bandsaw (1/2 HP)

400 mm (16") Throat

1 Circular Saw (1 HP)

250 mm (10") Blade, Tilting Table
Mitre Gauge, Fence, Guards

1 Drill Press (1/2 HP)

12 mm (1/2") Capacity Chuck, Variable Speed

1 Grinder (1/2 HP)

150 mm (6") Wheels, double ended

1 Metal Lathe (1/2 HP)

Bench Type, Screw Cutting Center Lathe, Variable Speed (40 - 1500 rpm), Reversing Switch, Gearbox and Automatic Apron, Centers placed at height of 100 mms (4") with 600 mms (24") between Centers:

- 3 Turning Toolholders (right hand, left hand, straight) with Bits
- 3 Parting Off Toolholders (right hand, left hand, straight) with Bits
- 1 Three Jaw, Self Centering Chuck and Backplate, 120 mm (5")
- 1 Four Jaw, Independent Chuck and Backplate, 150 mm (6")
- 1 Knurling Toolholder with Steel Knurls
- 1 Double Ended One Piece Boring Bar
- 1 Face Plate, 200 mm (8") diameter
- 3 Lathe Dogs, 6, 12, 25 mm (1/2", 3/4", 1")
- 1 Drill Chuck, 12 mm (1/2") capacity, with No. 2 M. T.
- 1 Rotating Center with No. 2 M. T.
- 1 Draw in Collet Attachment
- 1 Set of Collets, 12 mms (1/2") maximum size
- 1 Quick Change Tool Post
- 4 Quick Change Tool Holders

Further items are not essential. However, for those wishing to make their workshop facilities complete the following items may be added.

1 Buffing Machine (1/2 HP)

with R.H. and L.H. Extension Spindles,
Polishing Mop and Wire Brush

1 Oxy-acetylene Set (Very limited usage)

with Oxygen and Acetylene Regulators,
Welding Torch (with Tips), Cutting Torch
(with Nozzles and Cutting Guide), Hosing and
Goggles

1 Planer (1 HP)

15 cm (6") Blade, Tilting Table

1 Woodlathe (3/4 HP)

Centers located at height of 15 cms (6"), admitting 75 cms (30") between Centers. Complete with:

- 2 Handrests, 200 & 400 mms (8" & 16")
- 2 Face Plates, inner 200 mm (8") and outer 400 mm (16")
- 3 Centers (1 cone, 1 fork, 1 cup)
- 1 Set of Hand Turning Tools with long blades 150 to 200 mms (6" to 8")

7.3 Raw Materials

This list is not a complete itemization of all the raw materials used in a production workshop. It is simply an indication of the type of materials in constant use which would tend to form the basic stock of any production workshop, and which are worth ordering in limited quantities for any newly established workshop.

Adhesives

All Purpose Cement (Elmers, Duco)
Epoxy Resin & Hardener (Araldite)
Rubber Cement (Rugy)
Wood Glue (Weldwood)
Cellophane Tape
Plastic Tape

Electrical Materials

Bulbs with Holders (1.2, 2.5, 6.2 volts)
Dry Cells (1.5 volts)
Electrical Wire (Cotton or Plastic covered)
Fuse Wire (Assorted)
Magnet Wire (#20, 22, 24, 26, 28, 30, 32, 34)
Nichrome Wire (Assorted)
Parallel Electrical Cording
Plugs

Glass and Plastic

Acrylic (Plastic) Sheets, 2 cm and 2.5 cms thick
Plates (Glass), 56 x 56 x 0.3 cms (22" x 22" x 1/8")
Tubes (Glass), 3, 6 mms (1/8", 1/4") internal diameter)

Hardware

Bolts and Nuts

- Brass 3 mms (1/8") diameter, 12, 24, 48 mms (1/2", 1", 2") lengths; 5 mms (3/16") diameter, 24, 36 mms (1", 1 1/2") lengths
- Steel 5 mms (3/16") diameter, 12, 24, 48, 96 mms (1/2", 1", 2", 3") lengths
- Nails, 12, 24, 36, 48, 60, 72 mms (1/2", 1", 1 1/2", 2", 2 1/2", 3") lengths
- Sandpaper (00-2) and Carborundum Paper (120 - 500)
- Screws
- Cup Screws
- Wood Screws 12, 18, 24, 36 mms (1/2", 3/4", 1" 1 1/2") lengths
- Thumb Tacks
- Washers (Brass), 6, 9 mms (1/4", 3/16") diameter
- Wingnuts (Steel), 9 mms (3/16")
- Wire (Steel), #20, 26, 30

Lumber

Boxwood (Packing Case Material)
Hardboard, 6 mms (1/4") thick
Kiln Dried Wood, 2.5 x 15 cms (1" x 6") cross section
1.2 x 15 cms (1/2" x 6") cross section
Plywood, 6, 12 mms (1/4", 1/2") thickness

Metals

Bars

- Brass, 12 x 3 mms (1/2" x 1/8") cross section
- Mild Steel, 12 x 3 mms (1/2" x 1/8")
  18 x 3 mms (3/4" x 1/8")
- Tool Steel, 9 x 9 mms (3/8" x 3/8")
  40 x 40 mms (1 3/5" x 1 3/5")
- Spring Steel, Packing Case Bands

Rods

- Aluminum, 50 mms (2") diameter
- Brass, 2, 3, 9, 12, 18, 36 mms (1/16", 1/8", 3/8", 1/2", 3/4", 1 1/2") diameters
- Mild Steel, 6, 9 mms (1/4", 3/8") diameters
- Stainless Steel, 2 mms (1/16") diameter

Sheets

- Aluminum, 0.2, 0.4, 0.8, 1.6, 3.0 mms (1/100", 1/64", 1/32", 1/16", 1/8") thickness
- Brass, 0.4, 0.8, 1.6, 3.0 mms (1/64", 1/32", 1/16", 1/8") thickness
- Copper, 0.8 mms (1/32")
- Iron, 1.6 mms (1/16")
- Lead, 0.8 mms (1/32")
- Zinc, 0.8 mms (1/32")

Tubes

- Aluminum, 9, 12 mms (3/8", 1/2") internal diameter
- Brass, 5 mms (3/16") internal diameter

Paint Materials

Alcohol (Denatured)
Enamel (Black)
Enamel (White)
Lacquer, Clear
Lacquer Thinner
Paint Brushes
Paint Thinner
Primer
Putty
Shellac
Wood Filler

Miscellaneous

Aluminum Foil	Modelling Clay (Plasticene)
Carbon Paper	Paper Clips
Cartolina	Pens, Felt (Marking Pens)
Containers (Plastic or Glass)	Rubber Bands
Corks (Rubber or Cork)	Soldering Lead
Grease	Soldering Paste
Machine Oil	Straws
Metal Polish	String (Cord, Cotton, Nylon)

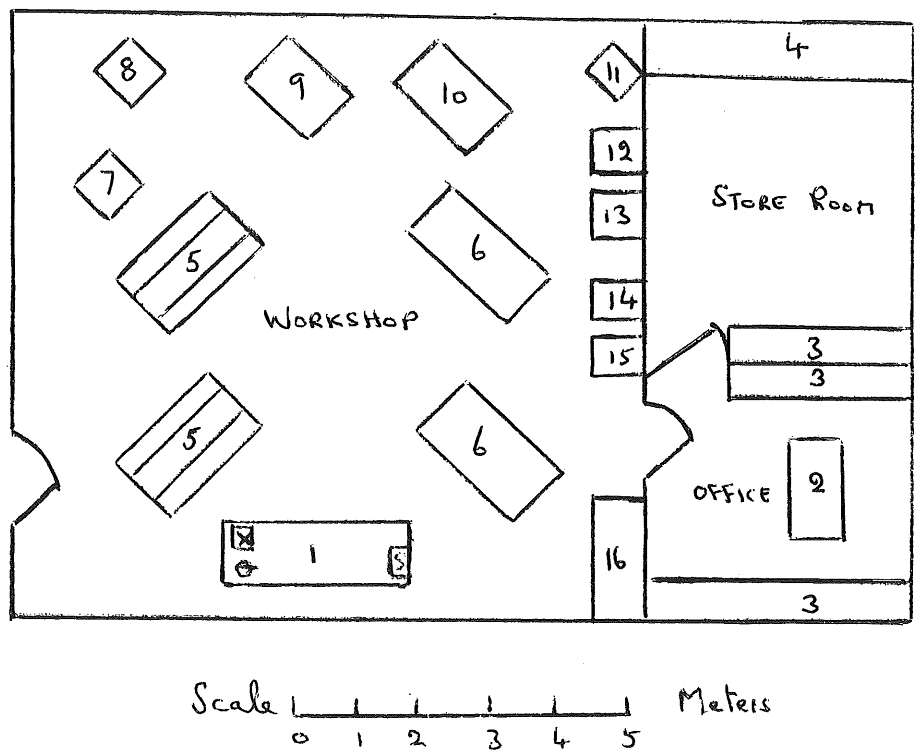
7.4 Adhesives

The following guidelines for fastening materials together should prove to be useful to those undertaking equipment making for the first time.

Material	Adhesive
Metals	
Aluminum to Aluminum	Rivets, Screws
Brass to Brass	Rivets, Screws, Solder
Copper to Copper (Magnet Wire)	Solder
Steel to Steel	Rivets, Screws, Solder, Welding
Steel to Brass	Rivets, Screws, Solder
Windings of Magnet Wire (layer to layer)	Varnish
Wood	
Glass to Wood (Ripple Tank)	Asphalt Based Cement
Metal to Wood	Screws
Wood to Wood	Screws, Wood Glue (Weldwood)
Miscellaneous	
Any Combinations of Materials e.g., Glass, Metal, Paper, Wood, etc.	Any All-Purpose Cement e.g., Duco Cement, Elmers Glue, Epoxy Resin & Hardener, Rubber Cement, etc.

7.5 A Workshop Plan

The following is the plan of the workshop in which the first complete set of 'Triple E Physics' materials was produced. It is not offered as an ideal layout. It was in fact somewhat cramped, but it proved to be more than adequate for the development of all the prototype equipment, and was considered large enough to produce a complete set of class materials.



1.	Experiment Table	11.	Metal Polisher (Horizontal)
2.	Office Table	12.	Grinder
3.	Storage Shelves	13.	Polisher (Vertical)
4.	Storage Racks	14.	Bench Drill Press
5.	Woodwork Benches	15.	Oxy-Acetylene Equipment
6.	Metalwork Benches	16.	Hand Tool Cupboard
7.	Circular Saw and Planer Combined	⊠	220 volt Electrical Outlet
8.	Band Saw		Gas Outlet
9.	Woordwork Lathe	S	Sink with Running Water
10.	Metalwork Lathe		

Electrical requirements depend on machines ordered, and may be single phase or 3 phase, and possibly both. Similar considerations affect the voltage provided.

8. LABORATORY FACILITIES

In designing a laboratory to meet local requirements several variables must be taken into consideration. These include the prevailing climatic conditions, local availability (or otherwise) of mains water, electricity and gas, the nature of experiments to be performed, the type of apparatus to be utilized, and the teaching techniques to be employed in the laboratory.

From country to country conditions of temperature, humidity, dust, prevailing winds, precipitation, and lighting vary considerably, and each individual country is the best judge of its own specific problems. In tropical countries, for example, the problem of humidity and temperature necessitates particular attention being given to cross ventilation to insure personal comfort for the student. This means that the creation of blackout facilities for optical experiments and ripple tank work gives rise to problems, if windows must be covered. One simple solution is to design apparatus to function efficiently under daylight conditions by using high powered light sources. For this the availability of mains electricity is a major asset.

It is important that consideration should be given to how laboratory facilities are to be used in practice. There is little point designing a laboratory for individual student experimentation if the cost of apparatus limits activities to class demonstrations. Equally well it would be wrong to procure small scale apparatus (intended for individual student use) if it was to be used for class demonstrations.

It follows that there is no single blue-print for a laboratory, and the design of the Economy Laboratory presented is simply one of many possibilities. This laboratory is primarily designed for a secondary school in a tropical country, and tackles the typical climatic problems that must be considered. It is also designed for small student group experimentation.

8.1 The Economy Laboratory

Layout

The size of the Economy Laboratory depends upon the maximum number of students likely to occupy the laboratory at any given time, space being allocated at the rate of approximately 3 square meters (33 sq. ft.) per student, an additional area of 10 sq. meters being provided for the workshop

preparation room. It is important to stress that in following an inquiring approach the teacher is normally very much in demand as a consultant, and, if the system is to work efficiently, class numbers must be kept to a minimum. It is realized that large classes are not uncommon in Developing Countries, but it is strongly recommended that every attempt should be made to limit laboratory classes to approximately 32 students, looking on numbers in excess of this as a temporary state of affairs.

Overleaf is a typical laboratory layout for 32 students (working in pairs) with 4 students at each table. (It would not be difficult to seat 48 students in the same laboratory by placing 6 at each table, particularly if the experiment tables were lengthened by 30 cms, and the laboratory size increased accordingly. However, a great deal would be lost by students working in larger groups, 3 to a group, and the temptation should be resisted).

The layout indicated is not the only possibility by any means, but whatever arrangement is chosen, it should be flexible, and should permit the teacher to circulate freely amongst the students at work, and should give ready access to apparatus cupboards. Location of windows should insure good lighting and cross ventilation (particularly in hot countries), and cupboards should be located accordingly. Above all, laboratory arrangements should be flexible, permitting regrouping of furniture according to the specific needs of the class. Four such re-arrangements are illustrated in the plans presented, indicating how the laboratory might be arranged for normal experiments, for ripple tank work and for discussion groups. Such flexibility cannot be achieved without paying careful attention to the design of laboratory furniture, and this is discussed in detail following the presentation of the floor plans.

LEGEND

A WINDOWS

B TABLE TOP WALL BENCH

C CUPBOARD

D DEMONSTRATION TABLE

E EXPERIMENT TABLE

W WORKBENCH

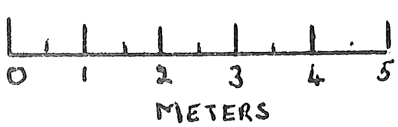
SH OPEN SHELVES

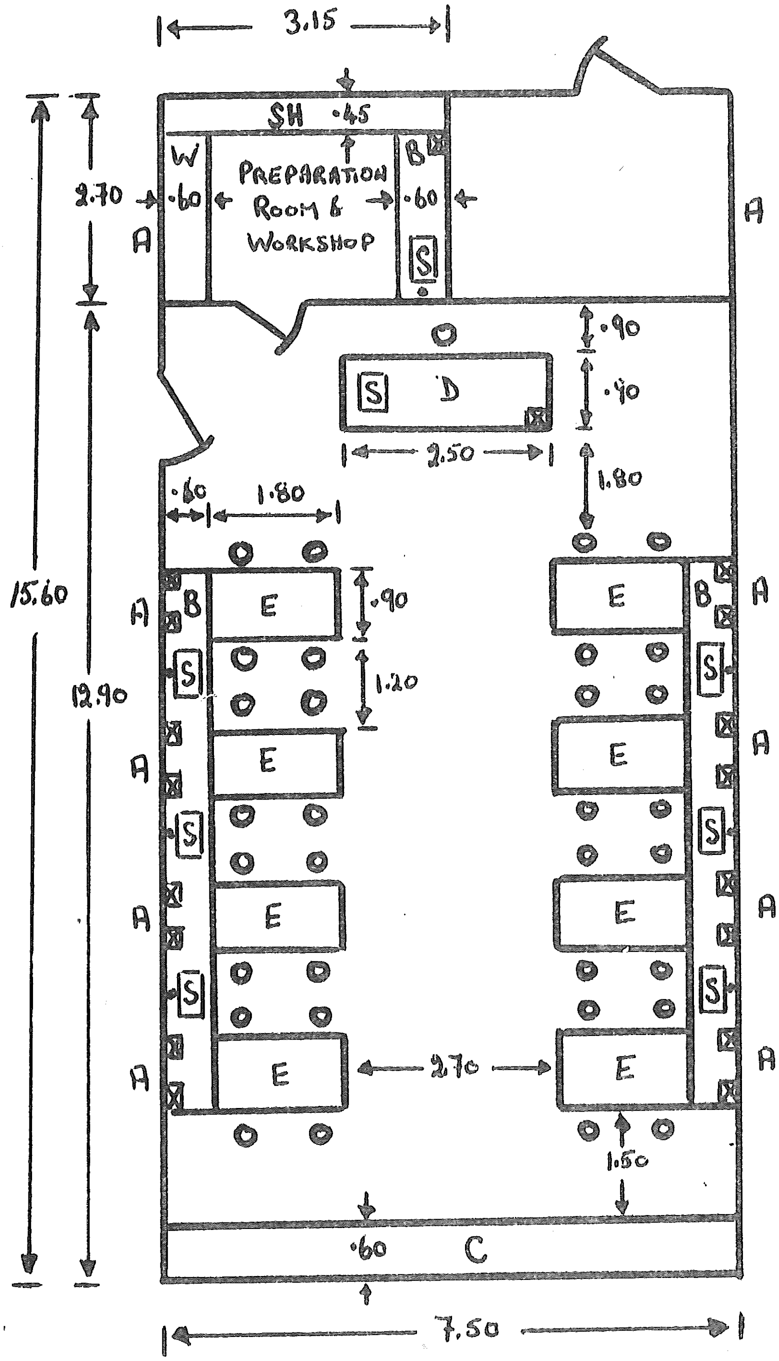
☒ ELECTRICAL OUTLET

O STOOL

S SINK WITH TAP

SCALE I CM = I METER





ECONOMY LABORATORY

Layout for normal experiments

LEGEND

A WINDOWS

B TABLE TOP WALL BENCH

C CUPBOARD

D DEMONSTRATION TABLE

E EXPERIMENT TABLE

W WORKBENCH

SH OPEN SHELVES

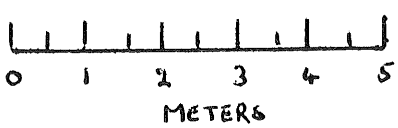
⊠ ELECTRICAL OUTLET

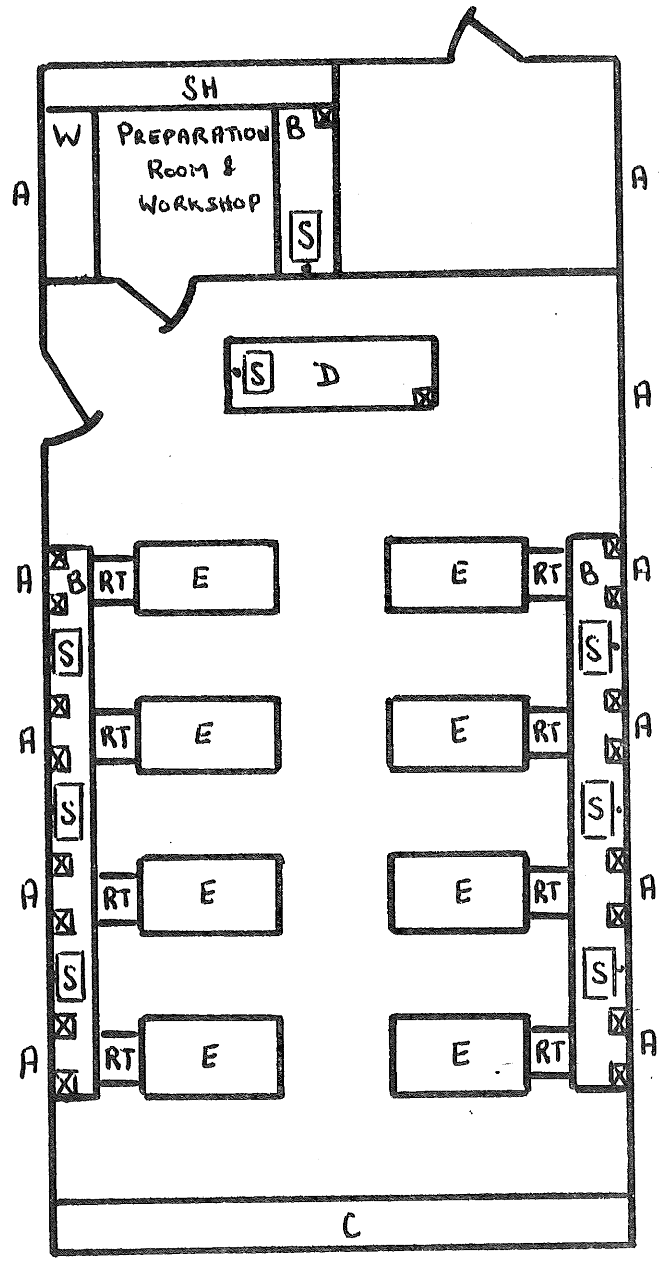
○ STOOL

$\boxed{S}$ SINK WITH TAP

$\boxed{RT}$ RIPPLE TANK

SCALE 1 CM = 1 METER





ECONOMY LABORATORY

Layout for Ripple Tank Work

LEGEND

A WINDOWS

B TABLE TOP WALL BENCH

C CUPBOARD

D DEMONSTRATION TABLE

E EXPERIMENT TABLE

W WORKBENCH

SH OPEN SHELVES

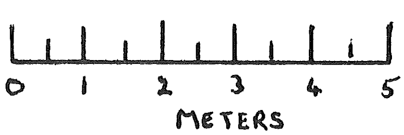
RT RIPPLE TANK

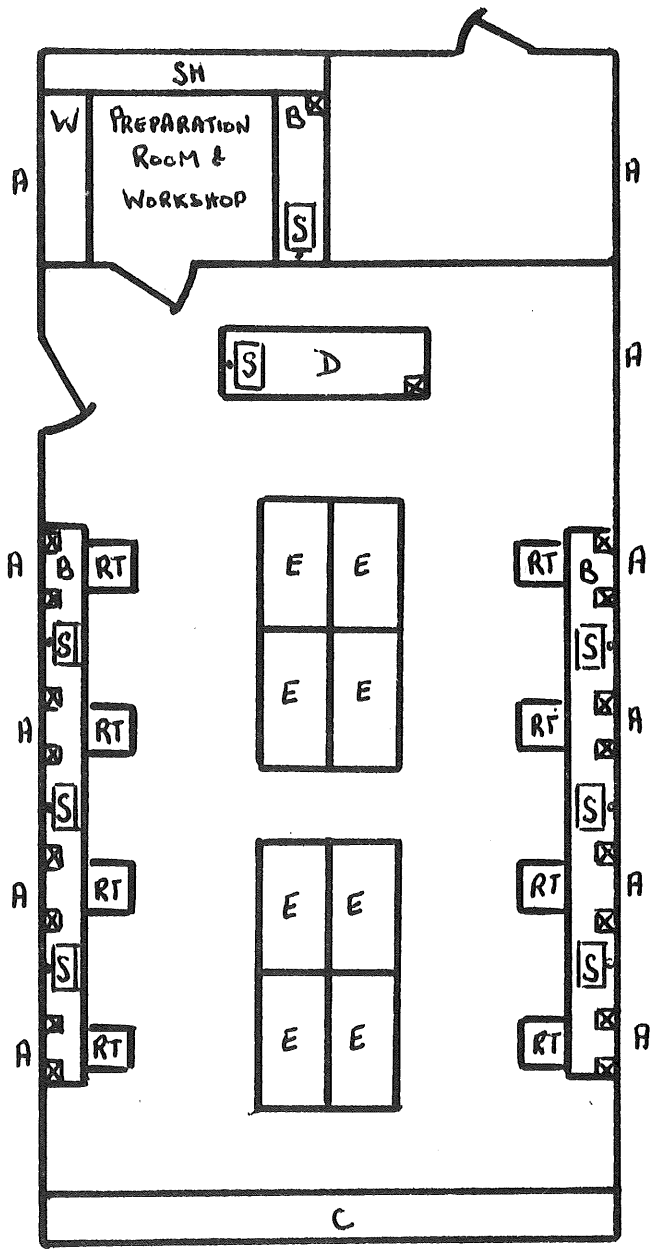
⊠ ELECTRICAL OUTLET

○ STOOL

S SINK WITH TAP

SCALE 1 CM = 1 METER





ECONOMY LABORATORY

Alternative Layout for Ripple Tank Work

LEGEND

A WINDOWS

B TABLE TOP WALL BENCH

C CUPBOARD

D DEMONSTRATION TABLE

E EXPERIMENT TABLE

W WORK BENCH

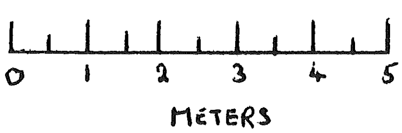
SH OPEN SHELVES

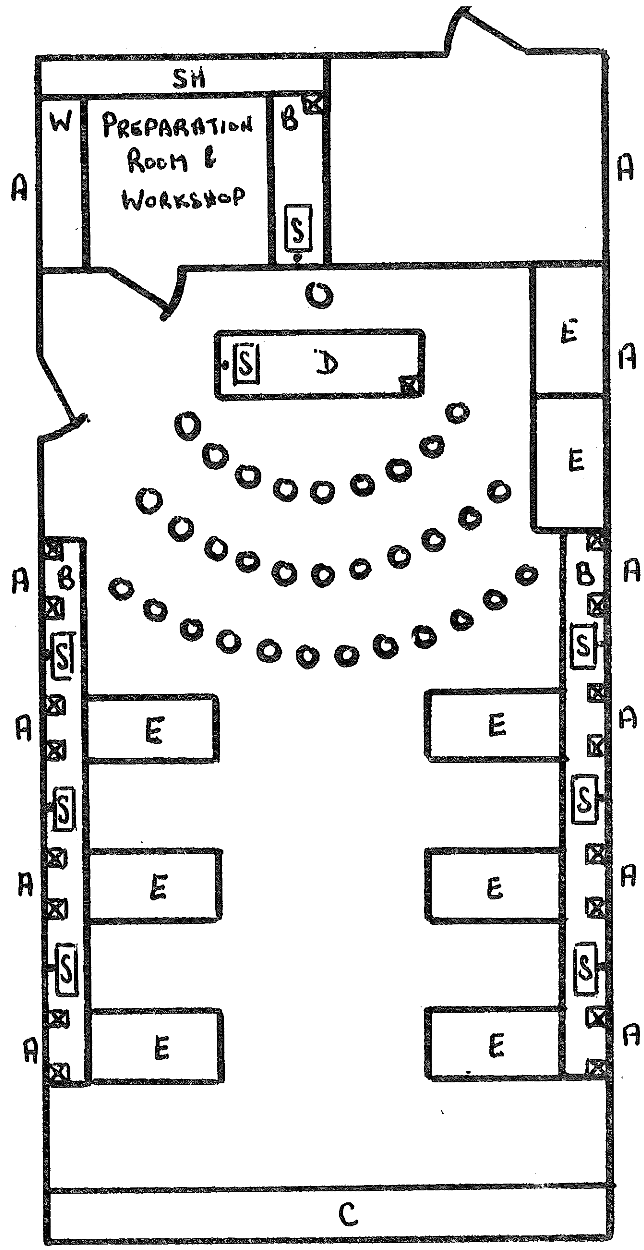
☒ ELECTRICAL OUTLETS

○ STOOL

[S] SINK WITH TAP

SCALE 1 CM = 1 METER



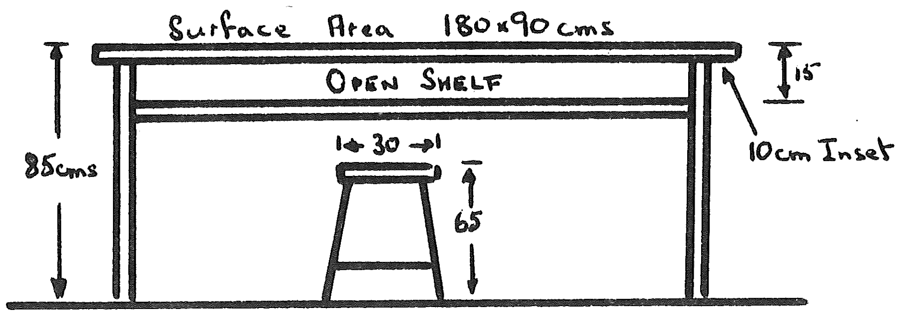


ECONOMY LABORATORY

Layout for Demonstrations and Discussion Groups

Student Tables

Although the student experiment table should be of sturdy design (with a good horizontal surface), it should not be fixed to the floor, whether deliberately, or accidentally (by water or electrical conduits), for it is intended as a mobile unit. A table top 180 x 90 cms is suitable for 4 students (working in pairs on either side of the table), particularly if an open shelf is provided for books, leaving the top surface completely free for apparatus. The height of the table is a matter of personal choice, and may vary from 75 to 90 cms, depending on the height of the student, and the teacher's philosophy. There is a tendency nowadays to prefer a high table, since a great deal of experimenting is done in a standing position with resulting discomfort if this necessitates a stooping position.



Student Experiment Table with Stool

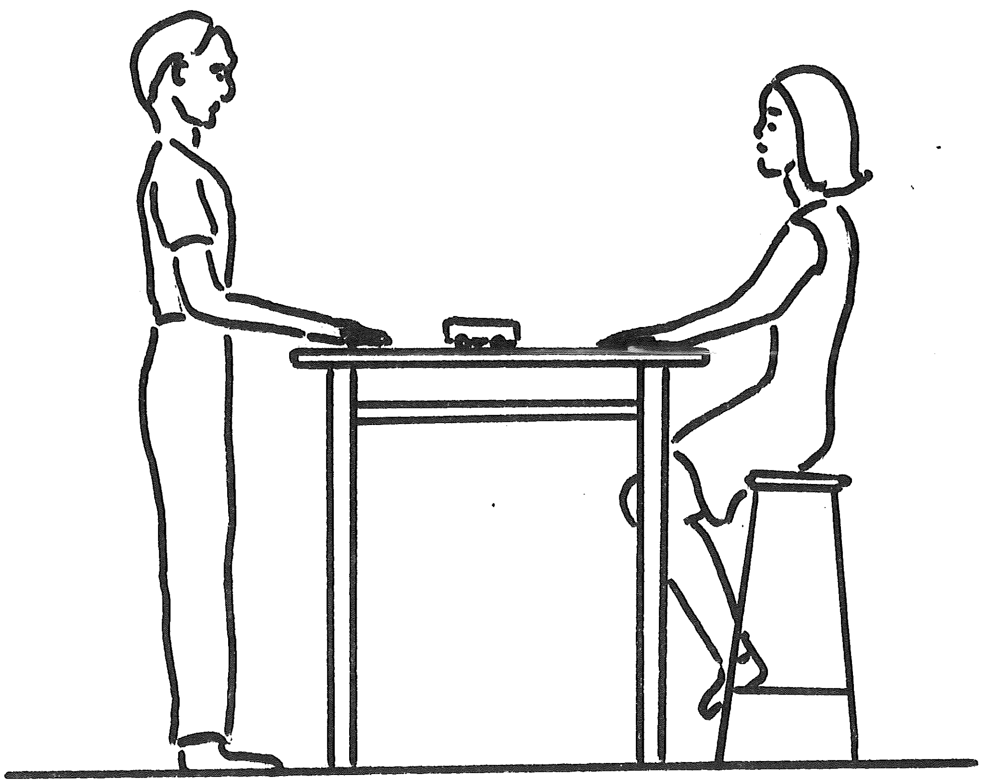
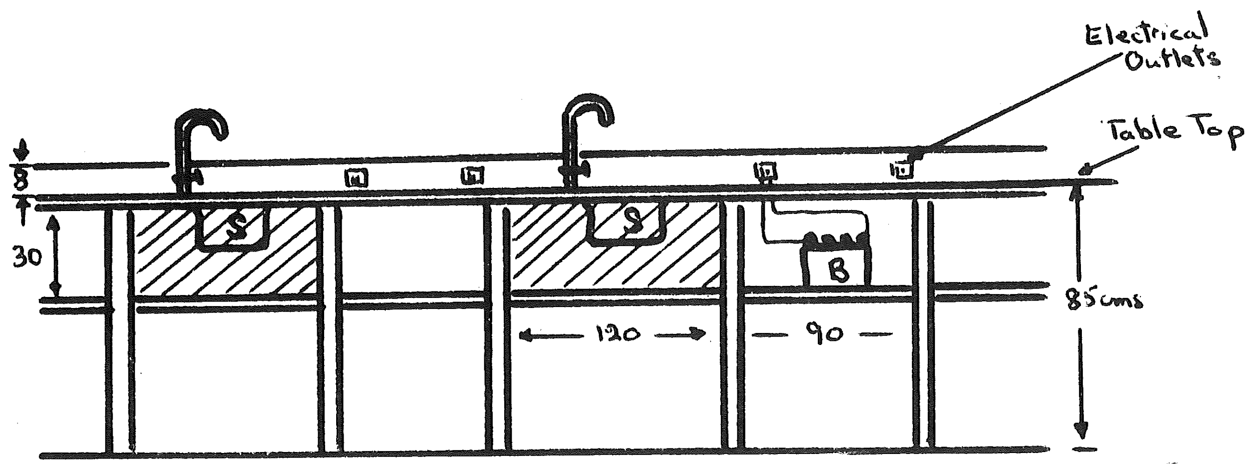


Table Height and Posture

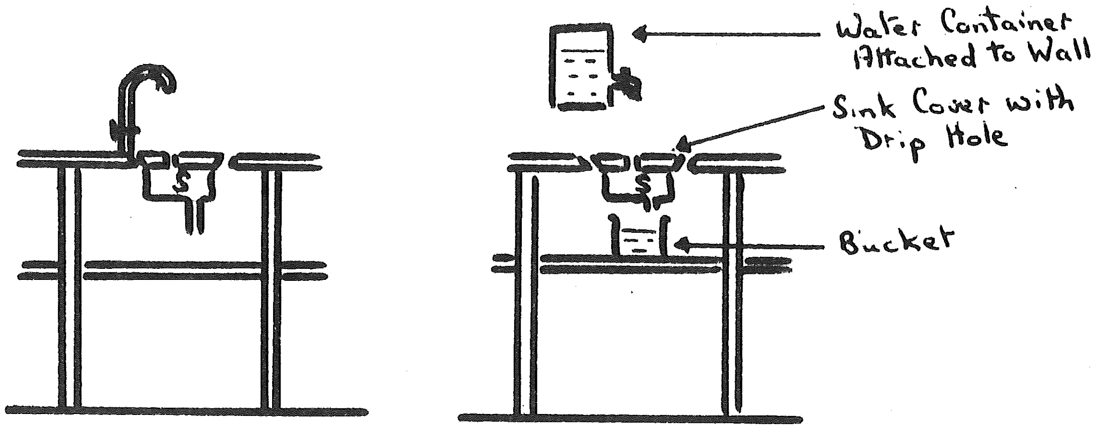
Table Top Wall Benches

The table top wall benches provide students with water and electricity outlets. The latter are used primarily as a means of illuminating ripple tanks and optical light sources. High wattage bulbs may be used if mains electricity is connected to the electrical outlets, thus permitting experiments to be conducted without blacking out the laboratory. Should mains electricity not be available, the same outlets may be supplied from 12 volt batteries, placed on the open shelf beneath the bench. Unfortunately, lower wattage bulbs must then be used, and at least partial darkening of the laboratory becomes necessary. This inevitably gives rise to additional problems in tropical countries. As an interim measure batteries may be extremely useful, but in the long term they are inconvenient and uneconomic, and should not be considered as a permanent solution to the electrical supply problem.



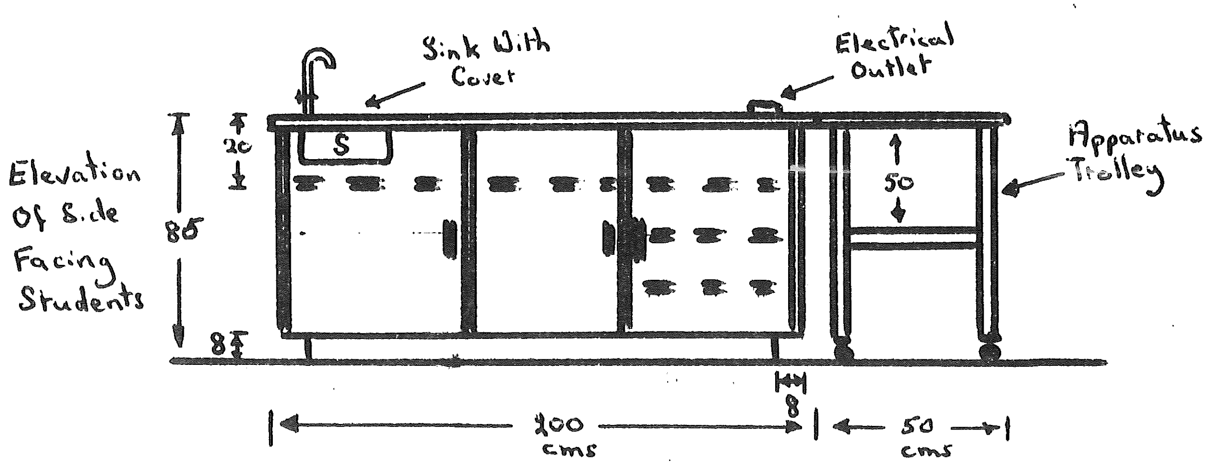
(Sink(S) hidden by front panel. Battery (B) wired to outlets if no mains electricity is available).

The table top wall benches may also be used for project work and standing displays, particularly if the uninterrupted top surface area is increased by the provision of wooden sink covers. Should a mains water supply not be available this need not act as a deterrent to experimental work. A water can placed above (or on) the bench can provide water, while a bucket beneath the sink can take it away. This, of course, is not as convenient as having tap water laid on, and should be considered only as an interim measure.

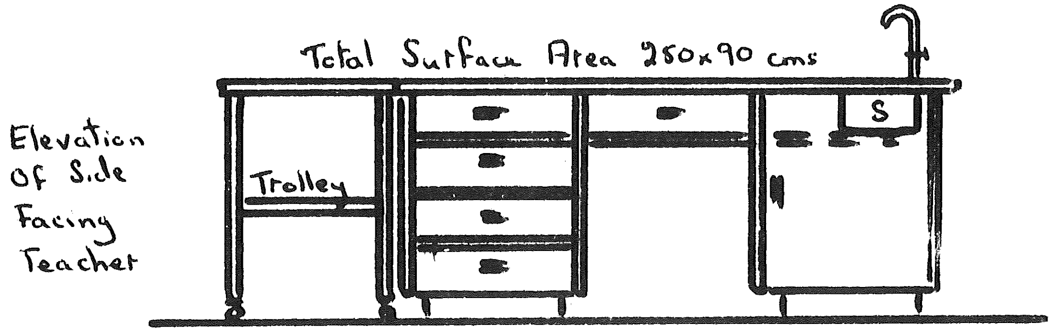


Demonstration Table

The teacher's demonstration table could be almost the same as the student experiment table, with the addition of a sink and electrical outlet (preferably 110 or 220 volts AC, but as already mentioned 12 volts DC could be used instead), but it is invaluable to include a few drawers and cupboards for extra storage space.



Demonstration Table

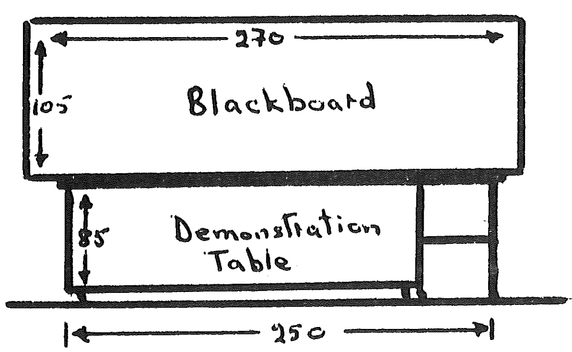


Demonstration Table

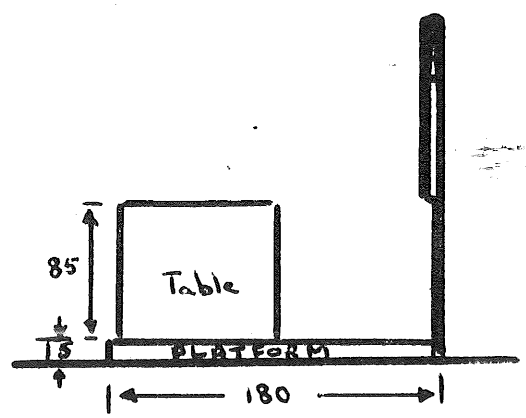
An apparatus trolley stored alongside the table usefully extends the demonstration surface, a small clip holding the trolley firmly to the table. Many teachers prefer the table to be elevated on a platform about 15 cms high. This is a matter of personal choice, but, if it is done, the trolley should be removed and the table extended to measure 250 x 90 cms.

Blackboard

The blackboard should be located on the wall behind the demonstration table, reaching from table top height (85 cms) to the full reach of the teacher. The higher the blackboard the better the visibility for the student, giving some justification to those who choose to place the demonstration table on a platform.



a) Without Platform

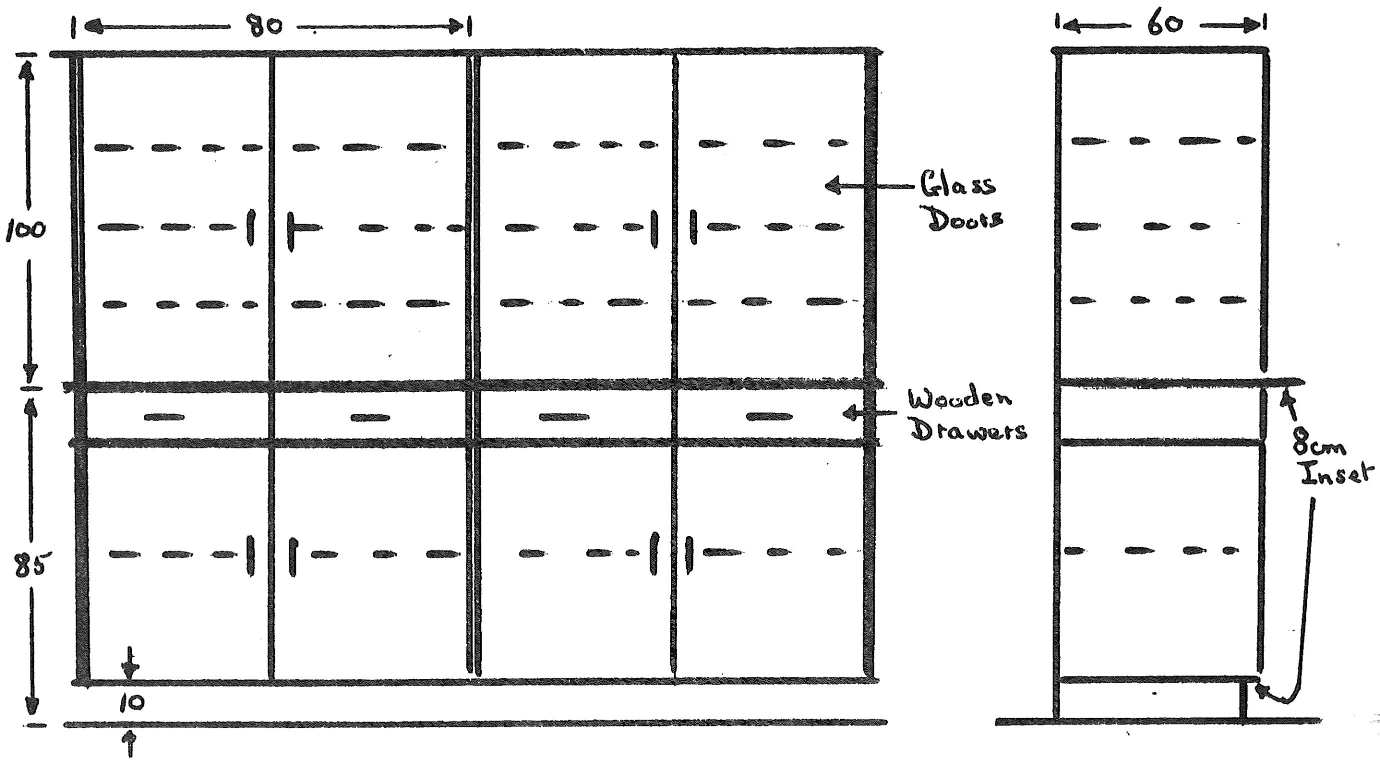


b) With Platform (370 x 180 cm)

Location of Blackboard

Cupboards

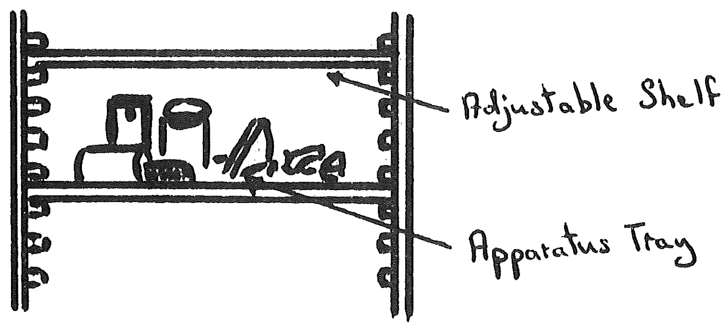
Many schools prefer to locate storage facilities in a separate store room for security, but if apparatus is to be used to the optimum extent it should be placed as accessible as possible, preferably in the laboratory itself. It is therefore well worthwhile securing the whole laboratory, rather than a single store room. The tendency to make cupboard doors of wood or metal, for security reasons, should be avoided, for apparatus is more readily located when the doors are of glass, and is therefore more likely to be used. Shelves could of course be left open, but doors do preserve apparatus by excluding grime and dirt.



Cupboards

They are also essential if humidity is to be controlled (as in tropical countries) by the location of a 40 watt bulb in one or more cupboards. In the long run the most important factor in preserving apparatus will be regular cleaning by the laboratory assistant. Cupboard shelves should

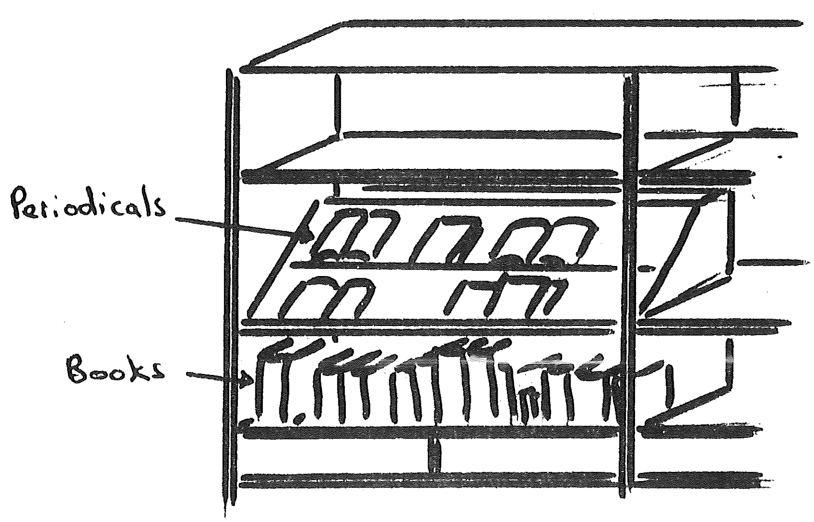
be adjustable to cope with varying sizes of apparatus, and to give flexibility of arrangement, while glass doors should be hinged so that shelves, or apparatus stores on trays (in class kits), can be removed from the cupboard without difficulty.



Adjustable Shelves

<u>Reference Library</u>

It is well worthwhile setting aside two shelves, for books and periodicals, to act as a class reference library. This should be a corner for stimulating reading, not for boring college textbooks. Readers written specifically for such programs as the "PSSC", "Nuffield O-Level Physics" and "Harvard Physics", and science magazines, of the caliber of "Scientific American", provide ideal reference material.



Reference Library

However, one should not overlook references such as biographies, which follow the trials and tribulations of scientists, or narratives which relate social progress to scientific advancements, both of which have considerable student appeal. Examples of such materials are:

a) "The Century of the Surgeon" by Jurgen Thorwald
"The Century of the Detective" by Jurgen Thorwald,
two "Reader's Digest" condensed books which not only capture the excitement and allure of science, but also depict its impact on society.

b) "Reviving Minds by Brain Surgery" by Dr. Hakim
An article from "Life Magazine" (May 1967) describing the discovery of a surgical treatment for hydrocephalus depending on Pascual's Law of Balancing Pressures.

c) "Madame Curie, First Lady of Science"
"Dr. Burkitt Tracks a Cancer Clue"
two articles from a "Reader's Digest" magazine (October 1968), the first a very human biography, and the second an excellent insight into the processes from which theories emerge.

Floor Insulation

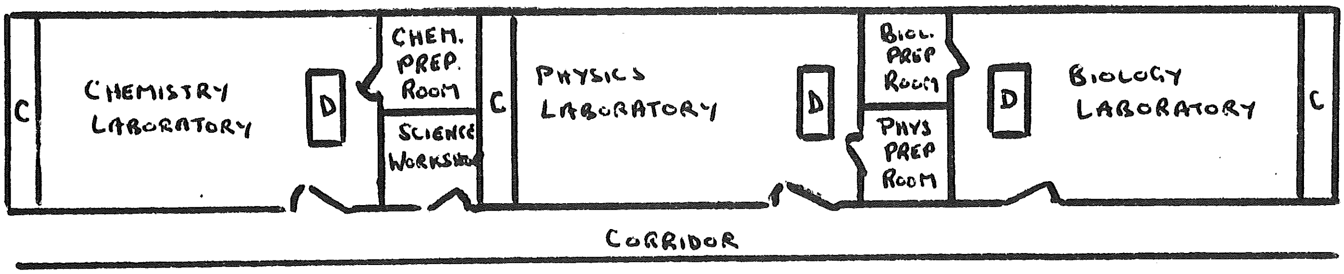
In finalizing the laboratory, note should be made of the fact that students may be using mains electricity (110 or 220 volts), and appropriate safety measures should be taken. It is a wise precaution to cover laboratory floors with an insulating material. Few schools will be able to afford vinyl floor covering, but many will be able to make use of local wood. Bare concrete, particularly when wet, can lead to dangerous accidents.

Workshop

Teachers with an aptitude for "tinkering", or provided with a laboratory assistant (technician), will wish to make full use of the workshop areas in the preparation room. The type of handtools and raw materials which might be found useful in such a workshop are listed under "Workshop Facilities" (Chapter 7).

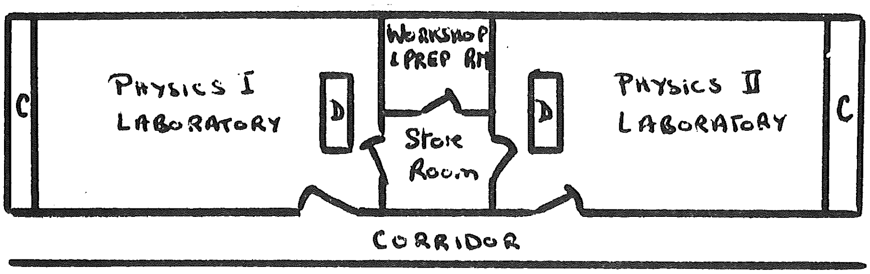
Science Wing

In developing a physics laboratory it is worth considering science requirements as a whole. Location of laboratories side by side not only insures optimum use of mutual facilities (such as the workshop), but also encourages cooperation between the individual scientific disciplines. A possible layout for a science wing is illustrated below. Large schools may require two laboratories for each scientific discipline, in which case



Science Wing

preparation and workshop facilities may be shared between two physics laboratories, with a mutual store room for more expensive items of equipment which the school cannot afford to duplicate.



Physics Wing

8.2 The Normal Laboratory

Most teachers will have noted that the Economy Laboratory omits several facilities normally found in more normal laboratories, and it is worth considering these separately, not only to convince the teacher of the adequacy of the Economy Laboratory, but also to indicate possible directions for future development.

Dark Room Facilities and Ventilation

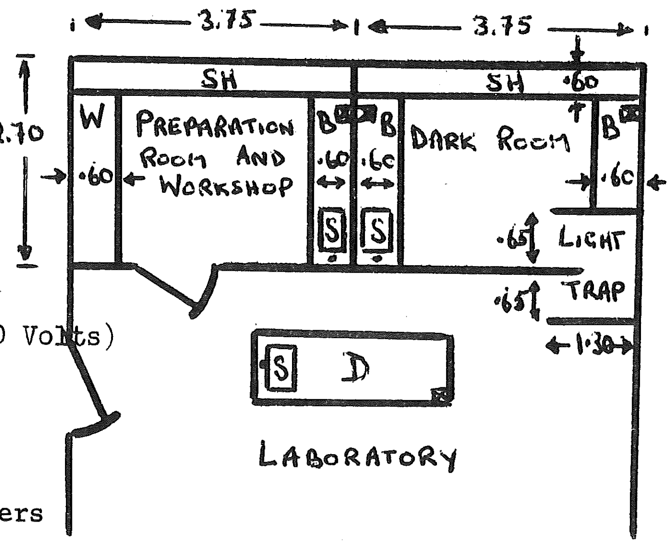
The most important omission is that of blackout facilities, or a dark room. Many optical experiments can be performed without difficulty in a normal, well lit laboratory, and a dark room is considered as a luxury item for the future, when photographic work becomes a normal part of the course, and more sensitive optical apparatus makes black out

LEGEND

- B — TABLE TOP WALL BENCH
- D — DEMONSTRATION TABLE
- SH — OPEN SHELVES
- W — WORK BENCH
- ☒ — ELECTRICAL OUTLET (110 or 220 Volts)
- S — SINK WITH TAP

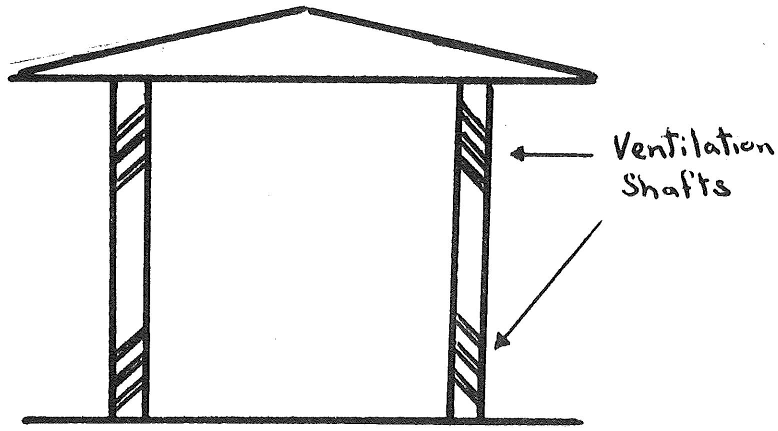
SCALE 1 CM=1M

0 1 2 3 4 5 Meters



Location of Dark Room

conditions essential. The space next to the preparation room would be ideal for such a future development. Schools in tropical countries would need to avoid eliminating ventilation in the dark room, despite the need to black out existing windows, and could achieve this to some extent by replacing the conventional door by a light trap, and by installing sloping ventilation shafts in the walls. The resultant blackout conditions would be adequate for most purposes, so long as the walls were painted with black matt paint.

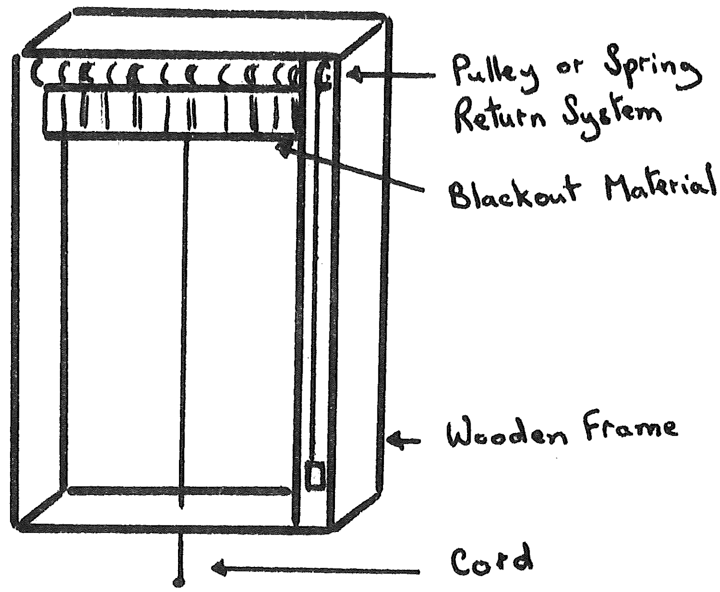


Ventilation Shafts

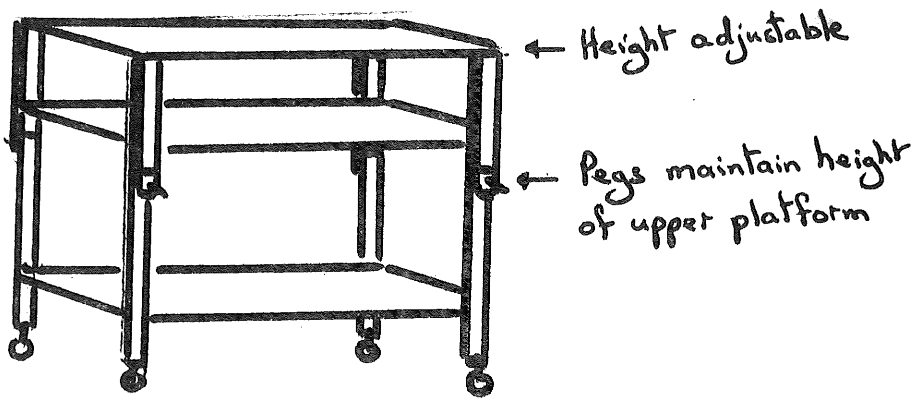
Blacking out the laboratory itself is another problem the teacher would have to face if projectors were to be used in the classroom. Such apparatus is considered beyond the means of the average school, but is worth considering for the future. Wooden louvres could exclude light reasonably well, but tend to continue to exclude too much light from the laboratory when actually open. Roller blinds would therefore be considered more suitable. Once again tropical countries would have to make provision for adequate ventilation by means of slanting ventilation shafts in the walls. The apparatus trolley, already referred to, could be used as a projector stand, particularly if the height of the upper surface could be adjusted, while a permanent screen located above the demonstration table would enable projection work to go ahead without relocation of students, encouraging greater use of such facilities.

Blackout
Material

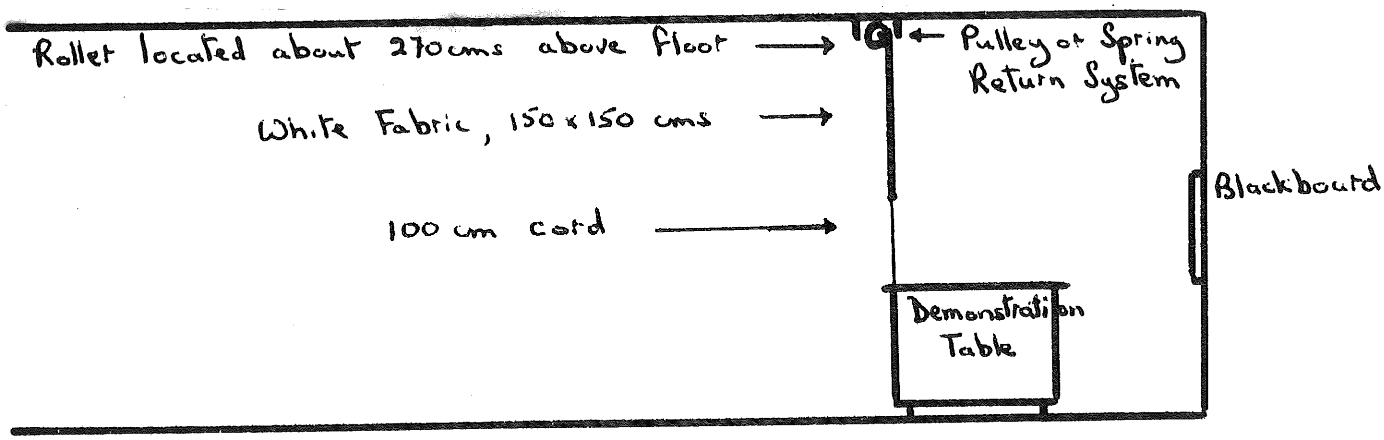
Wooden Frame



Roller Blind



Projector/Apparatus Trolley

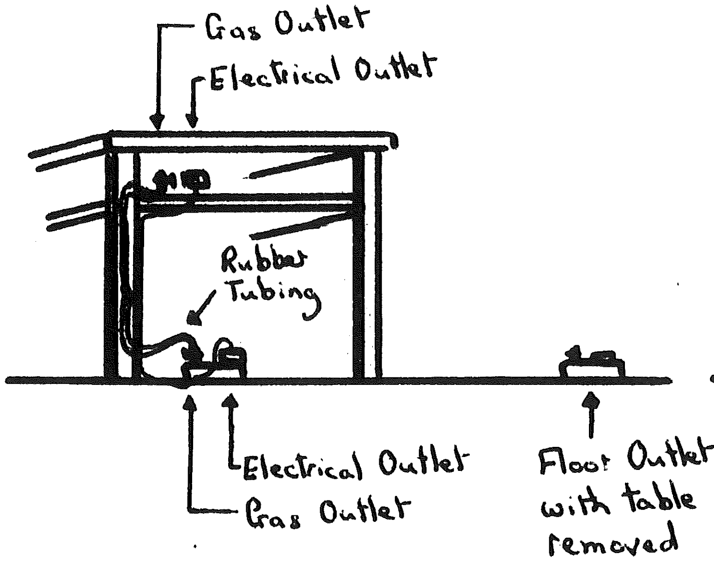


Projection Screen

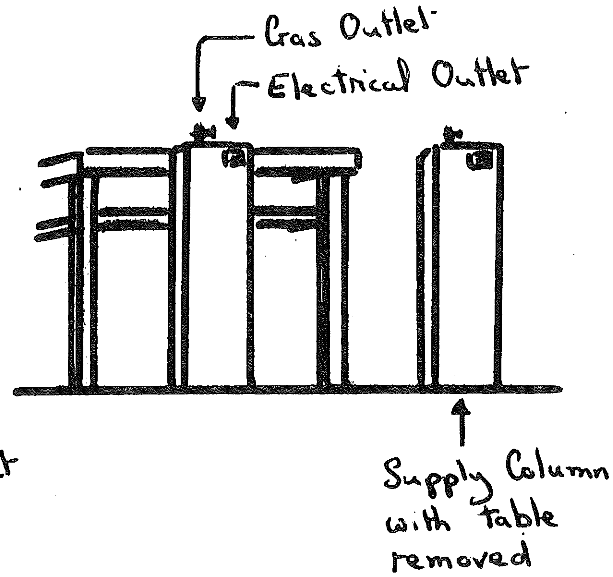
Mains Supplies

The Economy Laboratory would make use of simple alcohol or kerosene burners for most heating purposes. However, looking to the future most teachers would prefer to have gas available from either gas tanks or the mains, not only because of the convenience, but also because of the better flame that can be provided. Similarly the Economy Laboratory would make considerable use of dry cells for electrical experiments, but looking to the future it would be very useful to have a 10 volt DC supply in the laboratory. Such facilities might be installed at the teacher's demonstration table and in the workshop, where they would be extensively used, while extension to the wall benches and experiment tables would prove to be a most valuable addition.

Such facilities are included in the Normal Laboratory Plan overleaf. The layout presented could be identical to the Economy Laboratory already discussed, but interesting insights may be gained by presenting an alternative arrangement. The new layout would require somewhat greater space, but would have the advantage of students never sitting with their backs towards the demonstration table, so that short discussions and film projection would be possible without changing the seating arrangement. Students would also be somewhat more accesible to the teacher, and apparatus to the class. The major problem of such an arrangement would be in making gas and electricity supplies available to students without fixing the tables in permanent positions. This could be achieved by the use of raised floor outlets (as well as table outlets) with appropriate connections that could be disconnected. A better system would probably be that of using independent columns to carry the mains supplies to the tables. On moving the table the supply column would be left protruding, but would not be a deterrent to flexible arrangement of furniture.



Floor Outlets



Column Outlets

LEGEND

A WINDOWS

B TABLE TOP WALL BENCH

C CUPBOARD

D DEMONSTRATION TABLE

E EXPERIMENT TABLE

SH OPEN SHELVES

W WORK BENCH

ELECTRICAL OUTLET (110 or 220 volts AC)

ELECTRICAL OUTLET (10 volts DC)

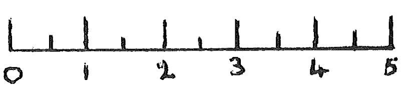
GAS OUTLET

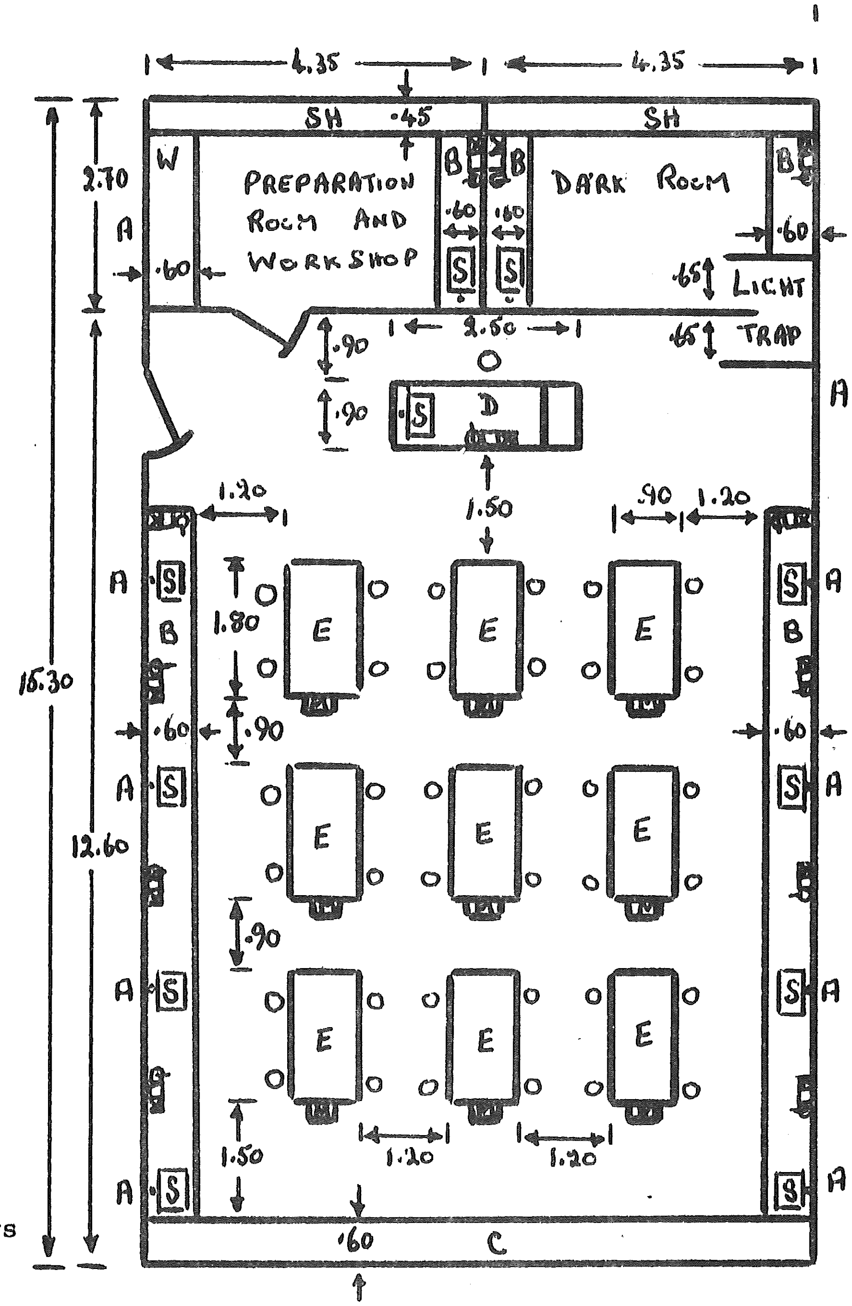
SINK WITH TAP

FLOOR OR COLUMN OUTLETS (Equivalent to)

STOOL

SCALE 1 CM = 1 M





Normal Laboratory Layout for Experiments

LEGEND

A WINDOWS

B TABLE TOP WALL BENCH

C CUPBOARD

D DEMONSTRATION TABLE

E EXPERIMENTAL TABLE

SH OPEN SHELVES

W WORK BENCH

☒ ELECTRICAL OUTLET (110 or 220 volts AC)

☐ ELECTRICAL OUTLET (10 volts DC)

GAS OUTLET

S SINK WITH TAP

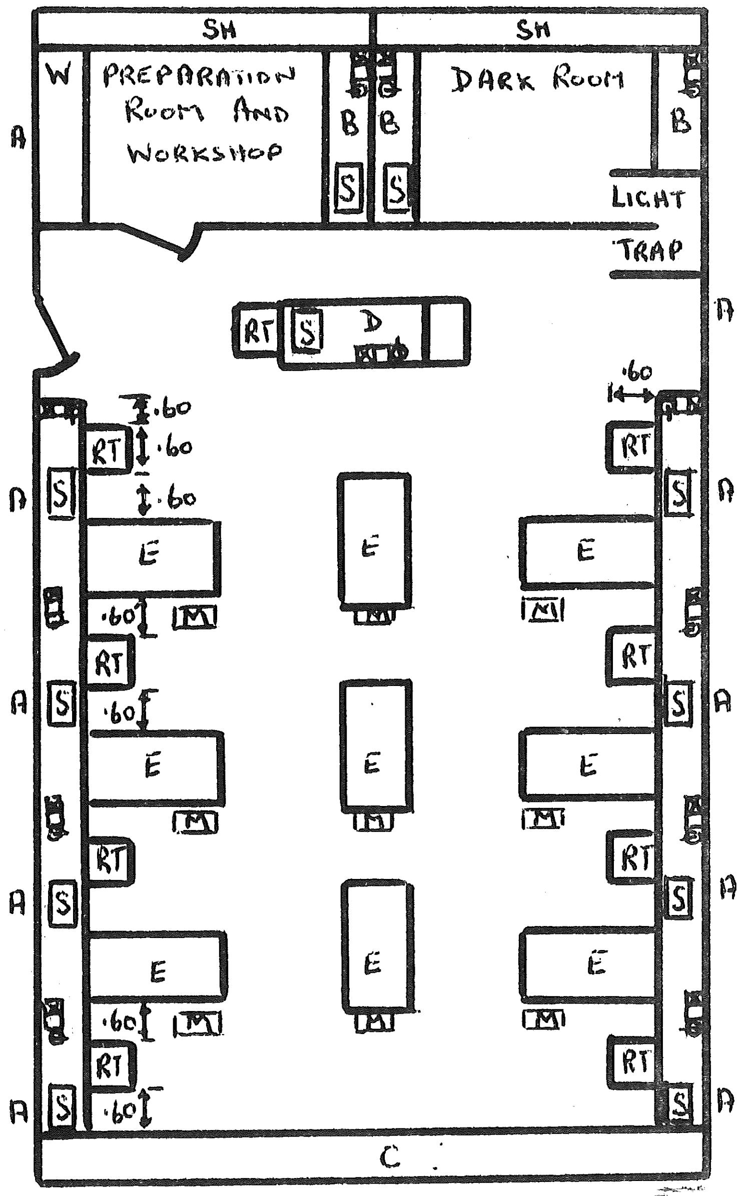
M FLOOR OR COLUMN OUTLETS (for 2 groups of students, equivalent to)

STOOL

RT RIPPLE TANK

SCALE 1 CM = 1 M

0 1 2 3 4 5 Meters



Normal Laboratory Layout for Ripple Tank Work

LEGEND

A WINDOWS

B TABLE TOP WALL BENCH

C CUPBOARD

D DEMONSTRATION TABLE

E EXPERIMENT TABLE

SH OPEN SHELVES

W WORK BENCH

ELECTRICAL OUTLET (110 or 220 volts AC)

ELECTRICAL OUTLET (10 volts DC)

GAS OUTLET

SINK WITH TAP

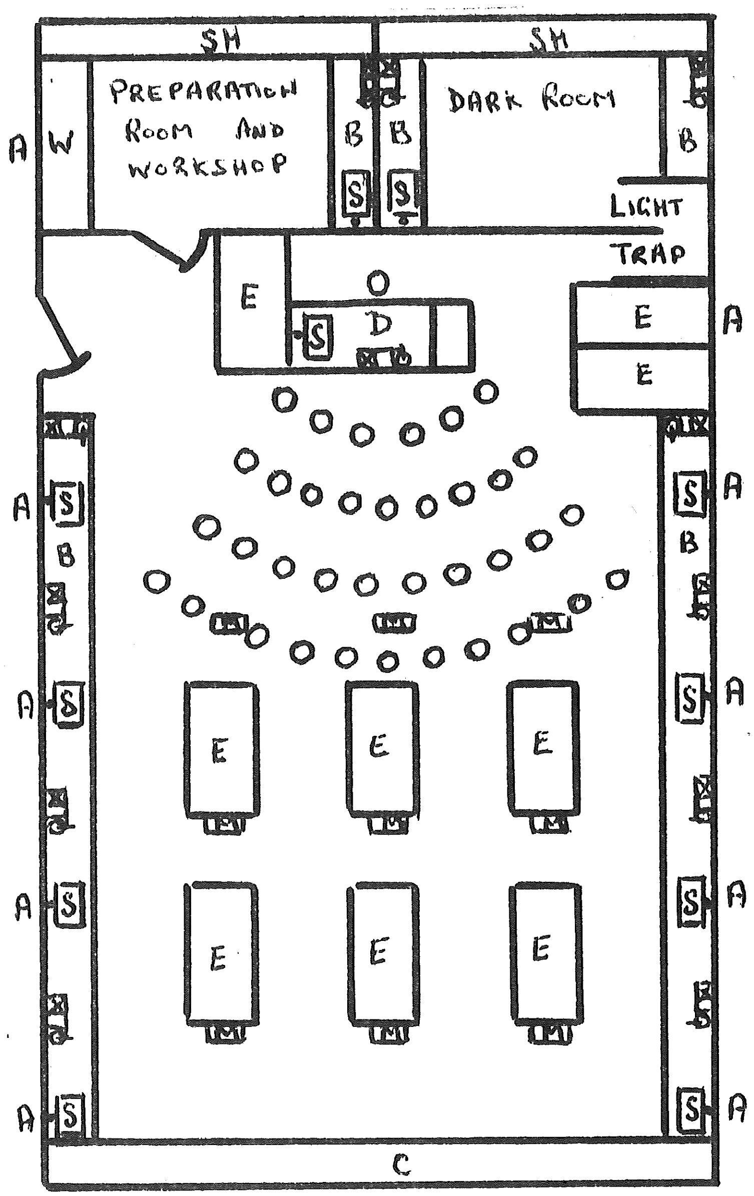
FLOOR OR COLUMN OUTLETS (Equivalent to)

STOOL

SCALE 1 CM = 1 M

Meters

0 1 2 3 4 5



Normal Laboratory Layout for Discussions

With such a layout the table top wall benches at the sides of the laboratory could be redesigned to include useful cupboard space below, while appropriate sections could be replaced by glass cupboards if additional storage was required.

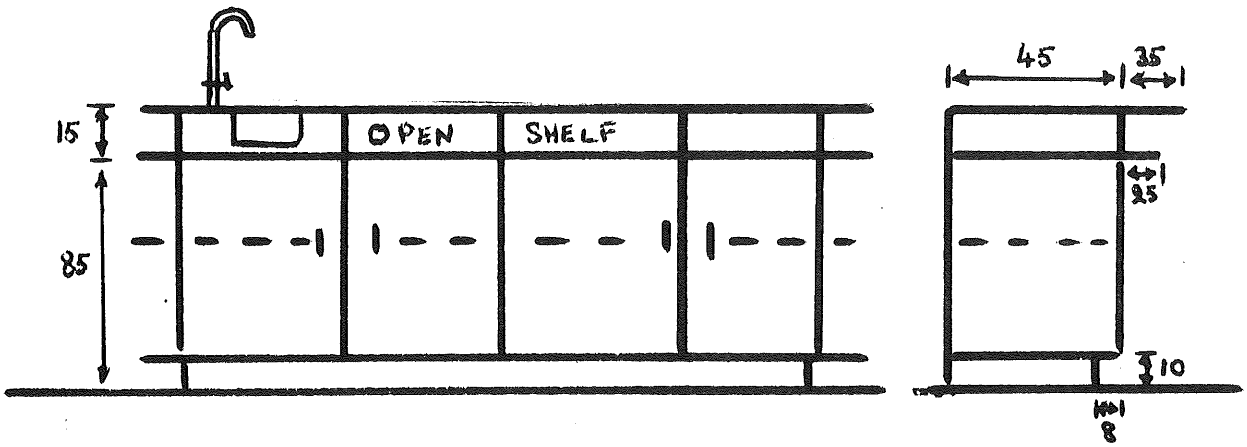


Table Top Wall Benches with Cupboard Space

In finally deciding what facilities should be developed the teacher should question the necessity, in each case, of the inclusion in the laboratory of the additional items generally found in the Normal Laboratory.